AD-A091 303 ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MS F/G 6/6
PROCEEDINGS OF THE ANNUAL MEETING (14TH) AQUATIC PLANT CONTROL --ETC(U)
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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Miscellaneous Paper A-80-3 (14)	2. GOVT ACCESSION NO. AD-A091303	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) (6) PROCEEDINGS, of the ~~14th~~ ANNUAL MEETING, AQUATIC PLANT CONTROL RESEARCH PLANNING AND OPERATIONS REVIEW, ~~26-29 NOVEMBER 1979~~ Held at Lake Eufaula, Oklahoma on 26-29 November 1979.		5. TYPE OF REPORT & PERIOD COVERED (9) Final report,
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s)		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U. S. Army Engineer Waterways Experiment Station ~~Environmental Laboratory~~ P. O. Box 631, Vicksburg, Miss. 39180		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Aquatic Plant Control Research Program
11. CONTROLLING OFFICE NAME AND ADDRESS Office, Chief of Engineers, U. S. Army Washington, D. C. 20314		12. REPORT DATE (11) Oct ~~ober~~ 1980
		13. NUMBER OF PAGES 389
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) (12) 393		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Aquatic plant control -- Congresses
Research planning -- Congresses

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The 14th Annual Meeting of the U. S. Army Corps of Engineers Aquatic Plant Control Research Program was held in Lake Eufaula, Oklahoma, on 26-29 November 1979, to review current research activities and to afford an opportunity for presentation of operational needs.

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PREFACE

The 14th Annual Meeting of the U. S. Army Corps of Engineers Aquatic Plant Control Program was held in Lake Eufaula, Oklahoma, on 26-69 November 1979. The meeting was organized by personnel of the Aquatic Plant Control Research Program (APCRP), Environmental Laboratory (EL), U. S. Army Engineer Waterways Experiment Station (WES).

The organizational activities were carried out and presentations by WES personnel were prepared under the general supervision of Dr. John Harrison, Chief, EL, and the direct supervision of Mr. J. Lewis Decell, Program Manager, APCRP. Mr. W. N. Rushing, APCRP, was responsible for planning and chairing the meeting.

COL Nelson P. Conover, CE, was Commander and Director of the WES at the time of this meeting and during the preparation of the proceedings report. Mr. F. R. Brown was Technical Director.

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ATTENDEES

14th ANNUAL MEETING
U. S. ARMY CORPS OF ENGINEERS
AQUATIC PLANT CONTROL RESEARCH PROGRAM

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AGENDA

14th ANNUAL MEETING
U. S. ARMY CORPS OF ENGINEERS
AQUATIC PLANT CONTROL RESEARCH PLANNING
AND OPERATIONS REVIEW

Lake Eufaula, Oklahoma

26-29 November 1979

<u>Monday, 26 November 1979</u>

10:00 a.m. to 6:00 p.m.	Registration, Lobby, Fountainhead Lodge
1:30 p.m. to 3:00 p.m.	FY 81 Civil Works R&D Program Review - R. F. Jackson, Office, Chief of Engineers (OCE), Presiding (Participation limited to CE personnel)
6:30 p.m.	Reception, Ballroom (Patio, weather permitting)

<u>Tuesday, 27 November 1979 - Ballroom</u>

8:00 a.m.	Registration continues, Lobby
8:30 a.m.	*Call to Order and Announcements* - W. N. Rushing, Waterways Experiment Station (WES)
8:35 a.m.	Welcome - COL Nelson P. Conover, Commander and Director, WES
8:45 a.m.	Welcome to Tulsa District - Mr. James P. Jones, Chief, Operations Division, USAE District, Tulsa, OK*
9:00 a.m.	Historical Sketch of the Aquatic Plant Control Research Program (APCRP) - COL Nelson P. Conover, WES
9:15 a.m.	Keynote Address - Mr. James Barnett, Executive Director, Oklahoma Water Resources Board
9:45 a.m.	Break
10:00 a.m.	Corps of Engineers Research and Development Program and Facilities - R. F. Jackson, Research and Development Office (RDO), OCE

* Presentation not submitted for inclusion in Proceedings.

10:20 a.m.	Research and Operations Interface in Aquatic Plant Management - H. R. Hamilton, Recreation Resource Management Branch, OCE
10:40 a.m.	Initial Plans for Aquatic Weed Research by the U. S. Environmental Protection Agency - G. E. Walsh, U. S. Environmental Protection Agency (EPA), Gulf Breeze, FL
11:00 a.m.	The FY 81 Civil Works R&D Program Review, and General Comments - J. L. Decell, Program Manager, APCRP, WES
11:30 a.m.	Lunch
1:00 p.m.	USAE Division/District Presentations - Aquatic Plant Problems - Operations Activities
	Lower Mississippi Valley Division New Orleans - Bill Thompson*
	North Atlantic Division - MAJ Paul Nelson*
	North Central Division St. Paul - Wayne Koerner
	North Pacific Division Seattle - Bob Rawson Walla Walla - Alden Foote*
	South Atlantic Division - Julian Raynes Jacksonville - Jim McGehee Mobile - Doug Nester Mobile (Lake Seminole Reservoir) - Joe Kight Savannah - Herb DeRigo
3:15 p.m.	Break
3:30 p.m.	USAE Division/District Presentations (Continued)
	South Pacific Division - Harry Dotson
	Southwestern Division Galveston - N. Joyce Johnson Tulsa - Jim Skaggs
	Unscheduled Presentations and/or General Question and Answer Session
4:30 p.m.	Summary of Day's Activities - J. L. Decell, WES

* Presentation not submitted for inclusion in Proceedings.

Wednesday 28 November 1979 - Ballroom

8:00 a.m.	Chemical Control Technology Development - H. E. Westerdahl, WES, presiding
8:10 a.m.	The Development of Controlled-Release Herbicide Technology Using Polymers - F. W. Harris, Wright State University, Dayton, OH
8:20 a.m.	Elastomeric Controlled-Release Herbicide Formulations - G. A. Janes, Creative Biology Laboratory, Barberton, OH
8:40 a.m.	Screening of Chemicals for Aquatic Plant Control - K. K. Steward, USDA, Fort Lauderdale, FL
9:00 a.m.	Fate of Fenac in the Aquatic Environment - H. C. Sikka, Syracuse Research Corporation, Syracuse, NY
9:20 a.m.	Floridone (Sonar) for Hydrilla Control - Russell Theriot, WES*
9:40 a.m.	Break
10:00 a.m.	Biological Control Technology Development - D. R. Sanders, WES, presiding
10:10 a.m.	Evaluation of Two Native Insects for Control of Eurasian Watermilfoil - G. R. Buckingham, USDA, Gainesville, FL
10:30 a.m.	Biological Control of Waterhyacinth, Hydrilla, and Eurasian Watermilfoil--A Progress Report - T. D. Center, USDA, Fort Lauderdale, FL
10:50 a.m.	Studies on Laboratory Rearing of *Arzama densa* - P. C. Quimby, USDA, Stoneville, MS
11:10 a.m.	Biological Control of Waterhyacinth and Hydrilla Using Plant Pathogens - T. E. Freeman, University of Florida, Department of Plant Pathology, Gainesville, FL
11:30 a.m.	Biological Control of Aquatic Plants in Puerto Rico - Leonce Bonnefil, Puerto Rico Department of Natural Resources, San Juan, PR
11:50 a.m.	Lunch

* Presentation not submitted for inclusion in Proceedings.

12:30 p.m.	Board buses for field trip to R. S. Kerr Reservoir, parking lot, front of Lodge. Trip includes Dutch treat dinner

Thursday, 29 November 1979

8:30 a.m.	Mechanical Control Technology Development - H. W. West, WES, presiding
9:00 a.m.	A Computer Model and Systems Cost Analysis of the Limnos Aquatic Plant Harvesting System - John Neil, Limnos, Ltd., Toronto, Canada
9:15 a.m.	Problem Identification and Assessment of Aquatic Plants - A. M. B. Rekas, WES
9:30 a.m.	Environmental Factors Affecting the Growth and Succession of Aquatic Plants - J. W. Barko, WES
9:45 a.m.	Break
10:00 a.m.	Large-Scale Operations Management Test Using Insects and Pathogens in Louisiana - D. R. Sanders, WES, presiding
10:15 a.m.	Progress Report of Field Applications - R. F. Theriot, WES
10:30 a.m.	Preliminary Studies with *Cercospora rodmanii* - E. A. Theriot, WES
10:45 a.m.	Large-Scale Operations Management Test of Prevention as an Aquatic Plant Management Method - R. L. Lazor, WES, and Florida Department of Natural Resources
11:05 a.m.	Barrier Screens for Eurasian Watermilfoil Fragment Control - D. Thayer, Okanogan County Weed Control, Oroville, WA*
11:15 a.m.	Laboratory Evaluations of Eurasian Watermilfoil Fragment Viability - M. A. Perkins, University of Washington, Seattle, WA
11:25 a.m.	Discussion
11:30 a.m.	Lunch

* Information presented by Thayer is included in the paper presented by Lazor.

1:00 p.m.	Large-Scale Operations Management Test Using the White Amur at Lake Conway, FL - E. G. Buglewicz, WES, presiding
1:15 p.m.	Aquatic Macrophytes - L. E. Nall, Florida Department of Natural Resources, Tallahassee, FL
1:30 p.m.	Fish, Mammals, Waterfowl - Roy Land, Florida Game and Freshwater Fish Commission, Tallahassee, FL
1:45 p.m.	Water Quality - Ray Kaleel, Orange County Pollution Control Board, Orlando, FL
2:00 p.m.	Benthos - T. L. Crisman, University of Florida, Department of Environmental Engineering, Gainesville, FL
2:15 p.m.	Herpetofauna - J. S. Godley, University of South Florida, Tampa, FL
2:30 p.m.	Ecosystem Modeling - K. C. Ewel, University of Florida, Department of Forest Resources and Conservation, Gainesville, FL
2:45 p.m.	Radiotelemetry Tracking of White Amur - M. P. Keown, WES
3:00 p.m.	Procedure for Radiotagging of White Amur for Tracking Studies - J. D. Schardt, Florida Department of Natural Resources, Tallahassee, FL
3:15 p.m.	Human Factors Study - R. R. Williams, WES
3:30 p.m.	Use of a Recording Fathometer for Determining Distribution and Biomass of Hydrilla - Michael Maceina, University of Florida, Gainesville, FL
3:45 p.m.	Aquatic Plant Control Activities in the Panama Canal Zone - S. D. Parris, WES
4:00 p.m.	Wrap-up - W. N. Rushing, WES
4:15 p.m.	Final Adjournment

14th ANNUAL MEETING

U. S. ARMY CORPS OF ENGINEERS
AQUATIC PLANT CONTROL RESEARCH PROGRAM

INTRODUCTION

As a part of the Corps of Engineers (CE) Aquatic Plant Control Research Program (APCRP), it is required that a research planning meeting be held each year to provide for professional presentation of current research projects, review of current operations activities, and review of new research proposals. The contents of this report include the presentations at the 14th Annual Meeting held in Lake Eufaula, Oklahoma, during 26-29 November 1979.

Historically, these annual meetings consisted of a series of presentations of technical papers on research conducted during the previous year. While these presentations proved very informative, there was a lack of desirable open exchange, on a discussion level, between researchers and operations personnel. Such an exchange was deemed necessary in order to define mission problems in such a context that future research objectives could be clearly identified and related to the operational elements' needs.

The first priority of the APCRP is technology transfer. The APCRP addresses four specific sectors in effecting this transfer. Each research effort conducted under the APCRP is required to report their technical findings to the U. S. Army Engineer Waterways Experiment Station (WES) each year in the form of quarterly progress reports, an in-progress review, and a final technical report. Each technical report is given wide distribution of over 400 copies as a means of transferring technology to the technical community. Timely results are periodically published and distributed through an APCRP Information Exchange Bulletin as a means of technology transfer to the general community, with a distribution of over 1000 copies. In addition, general public-oriented brochures, movies, and speaking engagements are available. Technology transfer to the field operations elements is effected through the conduct of demonstration projects in various District Office problem areas. Field manuals are being assembled to serve as the final product of technology transfer to this sector.

The printed proceedings of the annual meetings are intended to provide Corps management with an annual summary and guide to ensure that the research is continually being focused on current operational needs on a nationwide scale.

PROCEEDINGS

RESEARCH PLANNING CONFERENCE ON THE AQUATIC PLANT CONTROL RESEARCH PROGRAM

Historical Sketch of the Aquatic Plant Control Research Program

by

Nelson P. Conover*

The predecessor to the present Aquatic Plant Control Program (APCP) was known as the Expanded Project for Aquatic Plant Control, which was authorized by the Rivers and Harbors Act of 1965. At that time, research was conducted under the auspices of the expanded program. This was accomplished by the formation of a research advisory committee which held their first meeting in Galveston, Texas, on 13-14 October 1966.

In 1966, there were five research studies under way. These five efforts involved the U. S. Department of Agriculture, Crops and Entomology Division, the U. S. Department of Interior Fish and Wildlife Service, the Public Health Service of the Federal Water Pollution Control Administration, and the Universities at Auburn and Southwestern Louisiana.

These projects continued with no significant changes or additions until 1968. At that time, two efforts were added: research for the application of a CO_2 laser for control of waterhyacinths was initiated at Redstone Arsenal and Athens College, Alabama; and research for development of controlled-release herbicides was initiated at Edgewood Arsenal, Maryland, and Akron University, Ohio. The U. S. Army Engineer Waterways Experiment Station (WES) constructed the world's largest (and in all probability the only) floating CO_2 laser, and the field evaluation of this laser was completed in 1974. The studies to develop controlled-release herbicides were expanded during that time and now include Wright State University, the Creative Biology Laboratory, and Southern Research Institute. In 1969, research on the use of the white amur fish for control of submersed plants was initiated at Auburn University, Alabama. That same year, the Corps sponsored research at the U. S. Fish and Wildlife Service's fish farming experimental station at Stuttgart, Arkansas. This research resulted in the capability to spawn monosex populations of the white amur. The first such population spawned, as a result of the new technique, was used to stock Lake Conway in 1977 for

* Commander and Director, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

the presently continuing large-scale test.

In 1970, efforts were initiated at the U. S. Fish and Wildlife Service's pesticide research laboratory at Columbia, Missouri, and fish control laboratory, Warm Springs, Georgia, to study residues of 2,4-D in fish and shellfish. Later, studies pertaining to residues in water were undertaken at Northwestern University, Louisiana, and Syracuse Research Corporation, New York, and Virginia Polytechnic Institute, Virginia.

In 1973, the Office, Chief of Engineers (OCE), initiated major changes in the aquatic plant control program. The first of these changes resulted in the transfer of responsibility for technical monitoring from the Planning Division of OCE, to the Operations Division, Civil Works Directorate. Concurrently, the WES was designated as the Corps' lead laboratory for aquatic plant control research, placing responsibility for management of research at WES. This was the beginning of what is presently known as the Aquatic Plant Control Research Program (APCRP). With these changes came the mandate from OCE to elevate the program to a level commensurate with the national problem, giving technology transfer number one priority. Subsequently, major reorganization and emphasis was implemented for the research program.

The program was organized into its present structure of technology development areas with related research efforts, respectively, identified. Responding to the OCE priority for technology transfer, the concept of the Large-Scale Operations Management Test (LSOMT) was implemented. The first of these was the LSOMT for the use of the white amur, initiated in 1975 for the Jacksonville District. The second LSOMT was initiated for the New Orleans District in 1977 to implement the use of insects and pathogens for the control of waterhyacinths. In 1978, a LSOMT was initiated for the Seattle District to field test the concept of prevention as an operational control method. These LSOMT's are proving to be valuable technology transfer tools, while at the same time enabling operations personnel to initiate some level of control operations much earlier than would otherwise be possible.

Today the APCRP is conducting a total level of effort that is slightly more than five times the effort being conducted when WES was assigned as lead laboratory for aquatic plant control research. The program is now conducting 31 separate research efforts under the technology development areas. Through the 3 LSOMT's being conducted for the District Offices, 27 separate technical efforts are being addressed. Ten other subject areas are being conducted through the ongoing technology transfer and public information program. These efforts range from the importation of insects to the distribution of movies for use by interested civic groups.

Indicative of the significant progress made since 1975 is the fact that a 5-year research and development plan was formulated to provide program guidance for the period FY 75-80. Progress was so rapid that the APCRP reached the 5-year level and objectives in slightly over

2 years. This necessitated the revision of the plan and a new 5-year plan was developed covering the period FY 77-82. In FY 80, this year, we are exactly on target level of this present plan. Efforts have been initiated that will result in a new 5-year plan for the period FY 81-86. This new plan will reflect the increased capability and technical expertise that is now readily available to the APCRP as a result of becoming a part of the Environmental Laboratory at WES.

We expect that the growth of the program will continue for the next 3 years, but at a lessening rate. Requests from Districts for assistance are increasing and are expected to continue. This is believed to be due, at least in part, to two major factors. First, there is, in most areas, an increasing spread of many of the problem species. Second, there is an increasing awareness of the plants and our ability to recognize a problem. At the same time, the Corps has increased its capability to control some of the problems and, in some areas, can foresee the day when the control operations will become truly routine.

KEYNOTE ADDRESS

by

James R. Barnett*

As director of the Oklahoma Water Resources Board, the agency charged with developing, managing, and protecting this state's water resources, I'm concerned about any potential threat to our single most important natural resource, water. This in turn brings me to the primary topic of this meeting. Eurasian watermilfoil has exhibited more than just a potential threat to Oklahoma's waters. This aquatic plant's appearance here is of relatively recent vintage and thus most Oklahomans are not as aware of the problem as are the people of other infested areas--North Carolina, British Columbia, Canada, the Chesapeake Bay, and the Tennessee Valley Authority region. I'm sure that is also the case today. Many, if not most, of you are no doubt more familiar with this plant than I am. Even so, I would like to briefly discuss its history so as to hopefully set the stage not only for a more detailed discussion of our activities in Oklahoma but also for the other speakers that will be coming up on your program. I particularly hope to address how the plant can adversely affect our agency's accomplishment of its statutory responsibility of planning to provide for Oklahoma's future water needs.

Eurasian watermilfoil was discovered in the Tennessee Valley Authority (TVA) in 1960, and by 1968 it had spread throughout seven TVA reservoirs and covered approximately 25,000 surface acres of water. It has also invaded 67,000 acres of Currituck Sound in North Carolina and seriously damaged the area's previously excellent fishing. This is only one of the many ways in which this aquatic plant threatens beneficial water uses.

The plant can completely cover a body of water less than 15 ft in depth. Milfoil can damage or destroy a lake's recreational opportunities, rendering it unusable for boating, waterskiiing, and swimming and making it aesthetically unappealing. Fishing is difficult in infested waters, since lures can be lost if not retrieved fast enough. This is not to say that aquatic plants are not good for fishing--they are--it's just that you can have too much of a good thing! Another negative aspect is the fact that dense aquatic plant mats can and do retard fish growth resulting in stunted fish populations. Watermilfoil also interfers with water intakes and is a particular threat to cooling water intakes for power plants.

Eurasian watermilfoil was first discovered in Oklahoma in 1964 growing in Lake Humphrey in the southwestern corner of the state. By 1966, it had completely taken over the lake. Other early infestations were reported in Medicine Creek, Fort Cobb Reservoir, and Elmer Thomas,

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* Oklahoma Water Resources Board, Oklahoma City, Oklahoma.

Carl Etling, Shawnee, and Chandler Lakes--mainly in lakes in the western part of Oklahoma.

To date, watermilfoil has spread to many more lakes, but exactly how many and which ones remains a question. A 1978 survey showed 13 Oklahoma lakes infested with the plant. This question of how many are currently infested and to what degree is currently being addressed by the Corps of Engineers in a statewide study. The Corps' survey should reveal the distribution of watermilfoil to date and perhaps during this conference they can advise as to the current status of the study.

Since watermilfoil has already spread into the McClellan-Kerr navigation system, it is conceivable that it could continue to spread all the way from Tulsa to New Orleans via the waterway's barge traffic, if it hasn't already done so.

It should be noted that with the natural aging process of lakes associated with sedimentation, the lakes will become shallow and even more vulnerable to invasion by watermilfoil. The continuous threat of such infestations and the plant's adverse effect on various beneficial uses of water will undoubtedly result in immense economic losses. This of course raises the question, "How can the economic importance of milfoil control be evaluated?" It is my understanding that this is also a primary concern of the Corps of Engineers and they are currently developing a methodology for determining the economics of aquatic plant control. Perhaps we can also receive more detailed information on this issue during this meeting.

The Oklahoma Water Resources Board has been directly involved with two milfoil control programs: one on Fort Cobb Reservoir (a Bureau of Reclamation lake) in 1974, and another at Robert S. Kerr Reservoir on the McClellan-Kerr navigation system for the last 3 years. In each case, the Board's primary function was to evaluate the control program with regard to its impact on water quality. Both the responsible Federal Agency and the Oklahoma Water Resources Board wanted to know if the chemical control procedure using the herbicide 2,4-D had an adverse impact on water quality of the reservoirs.

After careful study, we reached the conclusion in three separate publications, copies of which are available in the rear of the room, that the use of 2,4-D did not adversely affect water quality. Thus, the results were deemed favorable for the continued use of the chemical in controlling the plant.

In January the Oklahoma Water Resources Board will submit to the legislature the Oklahoma Comprehensive Water Plan. This plan will propose distribution of water via a system of reservoirs and canals. I believe that with the development of a system that utilizes open canals and increases the exposure of water surfaces must also come the planning of an organized program for the control of watermilfoil.

CORPS OF ENGINEERS RESEARCH AND DEVELOPMENT CONTRIBUTIONS

by

R. F. Jackson*

Although the agenda indicates that I am to present a brief review of the Corps' Research and Development (R&D) Program and Facilities, a change in plan has been necessary and, instead, my remarks will consist of a short summary of some of the contributions that R&D is making and will make to the execution of the Corps' Civil Works program. The Civil Works R&D program addresses six functional areas as it seeks to completely underpin the Corps' Civil Works program. Approximately 1 percent of the Civil Works budget is devoted to R&D. Five Corps of Engineers laboratories, the Institute for Water Resources, and the Hydrologic Engineering Center perform R&D to solve pressing technical problems facing our Divisions and Districts. In every aspect of our Civil Works effort, we seek opportunities to apply R&D results.

Let me illustrate some of the ways in which R&D has contributed and will contribute to the execution of the Civil Works program. Research in support of the dam safety program has continued on a high-precision survey procedure that will detect movements as small as 3 mm in monolitic structures. Tests of this procedure were conducted at Grand Coulee Dam in July 1979. The first prototype instrument will be manufactured and installed at the Dworshak Dam in Idaho by June 1981. The present R&D effort is directed toward automation of the procedure with an expected capability of monitoring on command the upstream and downstream movement of up to 50 monoliths a day.

We are beginning to obtain results from the analysis and study of the large quantity of data collected in late 1978 during the DUCK-X coastal field experiment to gather ground-truth data with the NASA SEASAT Satellite. The experiment proved that spaceborn sensors can provide data for the coastal region for wave current and Gulf Stream effects, inlet hydraulics, and wind wave interactions.

Field, numerical, and analytical studies of research data on coastal inlets are being used to develop a physical model for the study of the shoaling problem at Little Lake Harbor for the Detroit District. Results of this model test will provide the basis for recommended inlet entrance modifications and possible jetty construction.

Results for the Coastal Engineering Research Center's (CERC) weir jetty study and the Murrels Inlet monitoring effort have been used to

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* Research and Development Office, Office, Chief of Engineers, Washington, D. C.

design a terminal groin structure for Tybee Island, Georgia. Shifting of the shoals in the Tybee Creek Inlet caused accelerated erosion of the restored beach.

Research on module system floating tire breakwaters in the CERC Large Wave Tank produced design guidance being used at Lake City, Minnesota, to design a floating tire breakwater for the marina on Lake Pepin. The lake is too deep and the bottom too soft for a conventional stone or steel structure.

The Ice Engineering Facility was completed in FY 79. The research program for FY 80 and model studies for Districts will fully utilize this facility. The large test basin is currently being used to investigate severe ice jam problems at the entrance to the St. Clair River from Lake Huron. Early results indicate that ice control structures such as ice booms will allow ships to transit this point and will substantially control the ice drift into the St. Clair River. The flume test facility has been used successfully to provide the Great Lake-St. Lawrence Seaway Winter Navigation Board with design for a water intake structure that is not effected by the accumulation of frazil ice. Laboratory developed underwater high flow air screens have been installed at Poe Lock, Saulte Ste. Marie, Michigan; at the Bonneville Lock on the Columbia River, Portland, Oregon; and at Lock 21 on the Mississippi River at Quincy, Illinois, to reduce passage of ice through the locks. The results of this initial ice engineering research will be published in Office, Chief of Engineers, Engineering Manuals in 1980.

A simple and inexpensive soil moisture sensor has been developed to improve our ability to predict spring snow melt runoff and flooding. Installation of the sensors can be tied to the GOES satellite system for obtaining the predictive data.

Results of research to determine causes of flow concentration and downstream scour have led to design modification for the stilling basins at the St. Francis Lake Control Structure and the Ditch 81 Structure in Arkansas.

Laboratory results of tests of riprap gradations are being transferred to the field for use such as a riprap channel on the Tennessee-Tombigbee Navigation Waterway Project. New research is directed at determining discharge, pressure, and water surface characteristics for spillway crest design not addressed in current hydraulic design criteria. Tests were performed on new fixed cone valves at the New Melones Dam, California, that operate under high heads to determine valve performance and to establish field operating procedures. In FY 80 the culmination of several years of hydraulic design R&D will be published in the revised Engineer Manual on the hydraulic design of reservoir outlet works.

The annual cost of corrosion damage to Civil Works structures is estimated to be $60 million. The Construction Engineering Research Laboratory (CERL) developed guidance that was used by the Walla Walla

District to design cathodic protection corrosion control systems for McNary, Little Goose, and lower Granite Locks and Dams. The cathodic protection system is also being developed by CERL to arrest the severe corrosion damage at the Thomas J. O'Brien lock on the Illinois Waterway. Simultaneously, CERL is conducting a structural analysis to assess the structural integrity of the damaged lock walls. These actions will assist in rehabilitation of the structure to restore its normal life span. A repair and replacement cost approaching $5 million will be avoided by this timely correction of the corrosion problem.

The CERL Paint Laboratory evaluated the cause of paint failure on the Bourne Bridge over the Cape Cod Canal for the New England Division and recommended a conventional paint system to arrest the problem in lieu of an extremely expensive vinyl system. The recommended paint was especially formulated to remove a lead primer to eliminate any possible contamination of the oyster beds in the area. The CERL Paint Laboratory continues to provide extensive consulting services for the Corps District and Division Offices. This past year the CERL Paint Laboratory responded to approximately 200 consulting calls and made 3 onsite evaluations.

In the early 1960's, CERL developed the existing coal tar epoxy specification accepted and published by the Steel Structures Painting Council. Recent research has developed an improved specification that will further reduce the cost and the availability of this product. This new specification has been accepted by the advisory committee of the Steel Structures Painting Council and will be adopted by the Council in the near future.

The Corps is committed to the use of airborne and spacecraft remote sensing technology to significantly reduce costs for the acquisition and monitoring of data. A new Remote Sensing Manual is scheduled for distribution in November 1979. This manual will present simplified guidance for managing and planning remote sensing missions. It will also provide an extensive summary of remote sensing principles, equipment, and image analysis with a cross-reference of past applications to assist new users in finding assistance for solving their problems. An example of the use of remote sensing technology to rapidly provide information at reduced costs is in the Corps' Aquatic Plant Control Research Program. The magnitude of a site-specific problem can be logically determined through the use of low altitude, high altitude, or satellite imagery missions. Imagery can then be automatically processed and maps produced showing species composition and distribution of plant infestations for use in planning control measures.

The Vicksburg District applied LANDSAT data for mapping water bodies, forests, and cleared areas in planning studies in the Yazoo and Tensas River basins to calculate the relationship of river stage to the area flooded. Historical trends were developed for land clearing using land-use data from aerial photographs from 1941 to 1969 and from LANDSAT data for the period 1972 to 1978. These data were then used to develop a computer program that simulates basin flooding and

stage-area flooded relations for nine separate flood stages. Flooded boundaries for each of the flood stages were plotted on overlays for standard topographic maps. These data overlays have been invaluable in determining the economic benefits of project alternatives and for presentation at public hearings. This flood simulation model represents a quantum leap in reducing costs and response time for Corps water resource planning studies.

An Airborne Laser Profiler System also is being developed to collect valley and stream cross-sectional data for use in flood forecasting and floodplain management. This system can reduce costs while gathering accurate data rapidly. The system could become operational early in 1980 if problems can be overcome with precise positioning of the aircraft.

The structural analyses of Civil Works projects have previously been hampered by complex loadings of earthquakes, intricate geometric configurations, and complex material behavior. The Finite Element Method is now being used for these analyses resulting in more reliable and economical designs. Examples of use of the Finite Element Method include verifying the seismic safety of the Savannah District's design for the Richard B. Russell Dam, eliminating the uncertainty about the earthquake security of the service bridge for the Uniontown Dam of the Louisville District, and establishing the structural safety of an aeration slot in the lower sluice of the Libby Dam to relieve a serious cavitation problem. The Finite Element Method was used efficiently and economically to design the chamber of the John N. Overton Lock and Dam for the New Orleans District to include a comprehensive analysis of the interaction between the structure and its pile foundation for various design load cases. A unique application of the Finite Element Method has been its use to establish temperature control plans for the construction of various concrete dams and navigation structures.

Cost savings will be realized in the Tennessee-Tombigbee Corridor Study for allocation of State and Federal resources to implement economic and human resource development programs by using the results of the McClellan-Kerr Arkansas River Navigation System Study, an area with similar social and economic circumstances.

Modeling efforts have produced design measures such as fins to straighten inflow, umbrellas to streamline inflow, and grids to eliminate severe air-entraining vortexes that rapidly damage pumps. The generalized pumping station research facility is being used to produce improved design criteria for arrangements and numbers of pumps for proper inflow and discharge hydraulics at typical small pumping stations and approach pump geometries. A model study of the Cache River Pumping Station verified the Memphis District design and recommended no major modifications. Extensive technology transfer is being made of this new information, mainly through the conduct of design conferences.

Assistance provided the Panama Canal Company to control and manage hydrilla in the Panama Canal determined that herbicides were extremely

effective to control the hydrilla infestations. The use of herbicides eliminated the use of copper sulfate which is toxic to aquatic animal life forms and much more expensive to apply.

Assistance was also provided to the Seattle District for testing methods to prevent the growth and spread of Eurasian watermilfoil. As mechanical harvesting operations are conducted in Canadian waters, watermilfoil is transported downstream into Washington. A barrier was installed in the Okanogan River designed to trap this floating watermilfoil.

The Dredged Material Research Program (DMRP) was successfully completed in March 1978. Since that time, technology transfer of program results has been accomplished by the Dredging Operation Technical Support Program. To date, over 100 requests from 27 Districts, Divisions, and OCE for assistance have been answered. The Chief of Engineers transmitted his final report to Congress in August 1979. Then OCE dispatched the final report to the State Governors and State Agencies to bring to their attention the availability of this advanced technology.

A Corps handbook was published in June 1979 describing techniques for conducting visitation surveys and for calculating attendance at Corps-managed recreational areas. These techniques will provide more uniform and consistent visitation data on which to support Corps recreation planning, management, and research functions. A report was also published providing guidelines for establishing carrying capacity levels and identifying techniques that address carrying capacity problems.

The Ohio Department of Natural Resources is preparing to construct recreational housing for 150 people at Deer Creek Lake. Our research with land treatment of wastewater at the Deer Creek Lake demonstration lagoon revealed a larger than expected treatment capacity. As a result, the existing lagoon system will be used by the State of Ohio with an expected savings of $350,000.

The Process Design Manual for the Land Treatment of Wastewater, published jointly by the Corps, the Department of Agriculture, and the Environmental Protection Agency (EPA) in 1978 has been revised to incorporate the latest research technology related to phosphorus and nitrogen removal, applications in forest ecosystems, and for determining infiltration rates.

A special report published in 1979 on "Building Salt Marshes Along the Coasts of the Continental United States" has provided guidance now being used by 8 Corps Districts to establish over 30 marshes. These marshes will provide wildlife habitat and afford bank stabilization for the coastline. A special report published in September 1978 on "Dune Building and Stabilization with Vegetation" provided a state-of-the-art technique that is now a fully operational engineering practice. Our Districts and Divisions are using this guidance to plant beachgrass in

conjunction with beach nourishment and sand stabilization projects and with hurricane protection projects.

The Environmental and Water Quality Operational Studies (EWQOS) continue to focus on the environmental effects of alternative designs and operational techniques for Civil Works projects. Physical models such as the Dickey-Lincoln School Lake project are used to obtain information during the preliminary design phase of a reservoir project. Studies of flow requirements and effects of flow and quality variations from hydropower projects on downstream fisheries are being conducted at Gilliam Lake (Arkansas), Hartwell Lake (Georgia/South Carolina), and other field study sites. The use of vegetation to reduce the environmental impacts of fluctuating reservoir pool elevations has been studied at Lake Wallula (McNary Dam in Washington) and other field sites. An Engineer Technical Letter will be published and distributed to Corps Field Offices in FY 80 summarizing guidance for the use of flood-tolerant plants for revegetation. Reaeration characteristics of outlet structures have been studied at Enid Lake (Mississippi), DeGray Lake (Arkansas), and J. Percy Preist Lake (Tennessee) with predictive equations developed and published for use in design. Techniques have been modeled to prevent nitrogen supersaturation at the Harry S. Truman Lake and to study various selective withdrawal configurations with a resulting improved predictative capability on their performance. The study of vertical jets in reservoirs in physical models provides data related to the use of destratification for improving reservoir water quality. Similar results were obtained from model studies of mixing and destratification techniques to improve reservoir water quality. Field studies at Clark Hill, Georgia, investigated aeration techniques for improving reservoir water quality. Field studies of Civil Works projects in waterways such as dikes and revetments on the Lower Mississippi River and navigation projects such as the Tennessee-Tombigbee Waterway continue to provide important information on environmental effects. Results of this research are being incorporated into hydraulic engineering manuals and into guidance for determining environmental impacts of water resources projects.

The Section 32 Program continues to investigate the nationwide streambank erosion problem. The U. S. Army Engineer Waterways Experiment Station (WES) published and distributed in July 1979 the interim report to Congress which outlines the effectiveness of a wide variety of bank protection methods. This program not only investigates the adverse effects of wave attacks and channel flow but research is devoted to determine the effects navigation craft have on streambank stability. Initial accomplishments in FY 79 include the completion of a model channel test facility and preliminary testing with a model twin-screw towboat and barges. Technology transfer of this research is accomplished twice annually through the Section 32 Steering Committee which has a representative from each Corps Division.

RESEARCH AND OPERATIONS INTERFACE

IN AQUATIC PLANT MANAGEMENT

by

H. Roger Hamilton*

Questions facing aquatic plant control problem solvers include:

_a_. Are results of our research effort reaching the proper people?

_b_. Are the results of our research being distributed in a timely manner?

_c_. Are the results of our research being distributed in a format which the intended audience can understand?

_d_. Are the research results being applied properly?

It all comes back to the basic questions that each problem solver must ask: who, what, where, when, why, and how? Technology transfer must be accomplished in a timely, informative, and skillful manner if it is to be successful.

What is technology transfer? Simply put, technology transfer is communication. Effective communication requires two parties. There must be a sender and the receiver for effective communication to occur.

Technology transfer forms the research and operations interface in the Corps of Engineers Aquatic Plant Control Research Program. Technology transfer also is accomplished in several forms. Some of the forms include:

_a_. Technical reports.

_b_. Newsletters or information exchange bulletins.

_c_. Brochures.

_d_. Movies.

_e_. Large-scale operations management tests.

_f_. Meetings.

The U. S. Army Engineer Waterways Experiment Station has published 46 technical reports to date. Currently, 12 more reports are in the publication process, making a total of 58 technical reports in the Aquatic Plant Control Research Program.

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* Chief, Natural Resources Management, Recreation-Resource Management Branch, Office, Chief of Engineers, Washington, D. C.

Two movies have been produced. Information exchange bulletins and brochures have received wide circulation. Additionally, certain Districts have published brochures and technical papers, conducted public meetings, and provided technology transfer in a number of ways. Seattle, Jacksonville, New Orleans, and Tulsa have been particularly innovative in this area.

The Corps' Aquatic Plant Control Program can be broken down into three distinct elements: research, planning, and operations. Each is a separate element, but each relates to the others. The interface, the need for effective technology transfer, is inescapable.

The Corps' organization within the continental United States is composed of the Chief's Office in Washington, 10 Division Offices, and 36 District Offices. We also manage 440 lakes, 22,000 miles of inland waterways, over 400 small boat harbors, and 3,000 miles of intracoastal channels. We also have laboratories such as WES which has been designated as the lead laboratory for aquatic plant control research.

We coordinate with other Federal, State, and local agencies, private entrepreneurs; conservation and environmental organizations; universities; and other interested groups and individuals.

We are in business for one purpose: to serve the public. Effective technology transfer is essential if we are to effectively and efficiently manage our program in the best interest of the public.

My feeling is that the interface between the various elements of the aquatic plant control program is operating in a satisfactory manner. But I do not like to operate on feelings alone. No matter how good a job we are doing, we still have room for improvement. I, therefore, have designed a questionnaire which I would now like to distribute to you. If you will complete this questionnaire and return it to me immediately it will be very helpful in ensuring that our program is managed in the public interest.

Questionnaire
Aquatic Plant Control Research, Planning, and
Operations Meeting - Lake Eufaula, Oklahoma
26-29 November 1979

1. I represent:

   U. S. Army Corps of Engineers
   Other Federal Agency
   State Agency
   Local Agency
   Private Company
   University or College
   Other (Describe)____________________

2. The method of control with which I am most concerned is:

   Chemical
   Mechanical
   Biological
   Integrated
   Physical Manipulation
   Other (Describe)____________________

3. My work pertains primarily to:

   Planning
   Research
   Control Operations
   Policy/Administration
   Marketing
   Engineering and Design
   Other (Describe)____________________

4. I receive aquatic plant control research publications produced by the Corps of Engineers:

   As they are published (I am on the mailing list)
   Frequently
   Occasionally
   Not at all

5. I read these publications:

   75-100% of the time
   50-75% of the time
   25-50% of the time
   0-25% of the time

6. I find the material in the publications informative and useful in my work:

75-100% of the time
50-75% of the time
25-50% of the time
0-25% of the time

7. I am familiar with the Large-Scale Operations Management Tests (LSOMT) being conducted by the Corps in cooperation with others.

Yes
No

If the answer to question #7 is yes, respond to questions 8 thru 11.

8. I think the LSOMT is an effective means of technology transfer:

Yes
No, because:

9. I, or my organization, have benefited from LSOMT:

Yes
No

10. Research and operations problems being addressed currently by LSOMT are appropriate for this type of technology transfer:

Yes
No

11. Other topics which should be addressed by LSOMT include: (List below)

12. Overall management of the aquatic plant control program by the Corps is:

Excellent
Adequate
Less than adequate
Totally inadequate

13. Current legislation for the Corps' aquatic plant control program is:

Adequate
Inadequate
I am not familiar with legislation

14. The following legislative changes should be made:

15. Current policy for the Corps' aquatic plant control program is:

Adequate
Inadequate
I am not familiar with policy

16. The following policy changes should be made:

17. The Corps should establish a Center of Competence for aquatic plant control:

Yes
No

18. The following aspects of aquatic plant control should receive greater emphasis from the Corps:

19. The current technology transfer aspect of the Corps' aquatic plant control problem is:

Excellent
Adequate
Less than adequate
Totally inadequate

20. Please rate the technology transfer aspect of the Corps' aquatic plant control program below by placing a checkmark on the line which, in your mind, best reflects the performance.

Totally Inadequate				Average					Fully Responsive
1	2	3	4	5	6	7	8	9	10

21. Additional comments. Use another sheet of paper if needed:

Please return to:

H. ROGER HAMILTON
Chief, Natural Resource Management
U. S. Army Corps of Engineers
Washington, D. C.

INITIAL PLANS FOR AQUATIC WEED RESEARCH BY THE U. S. ENVIRONMENTAL PROTECTION AGENCY

by

Gerald E. Walsh*

Introduction

The Environmental Protection Agency (EPA) has been authorized, under the Federal Water Pollution Control Act, to "develop environmentally sound methods to control aquatic weeds" (H. R. 2676; Congressional Record, Nov. 9, 1979). Proponents of the bill further stated: "The conferees intend that a research program be conducted with the purpose of eventually providing environmentally sound solutions to the problems of aquatic weed control." We plan to approach the problem from several aspects with a view toward testing and developing environmentally sound methods for weed control. The aspects include chemical, biological, mechanical, integrated, and sequential control methods and their effects upon aquatic systems.

Development and testing of methods for aquatic weed control have been carried out by the U. S. Army Corps of Engineers, the U. S. Department of Agriculture, and other Federal and State agencies for many years. However, research is needed with regard to environmental impacts of weed control practices, and EPA, under its broad congressional mandate, can work closely with Federal, State, county, and university personnel on the problems of weed control.

The EPA has little experience in control of aquatic weeds, except in registration of herbicides for aquatic use. It has been necessary to learn what has been done, what the current problems are, and what the future needs will be with regard to weed control. With help from leaders in the field, we have developed a comprehensive research plan that is nationwide in scope. The plan is designed to (a) complement and extend current work by other Federal and State agencies, and (b) initiate research programs unique to EPA that promote and assist development of environmentally safe methods of aquatic weed control.

Objective

The EPA research plan is designed to develop environmentally acceptable methods for aquatic weed control for practical application at

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* U. S. Environmental Protection Agency, Environmental Research Laboratory, Gulf Breeze, Florida.

the local level. This objective will be achieved through a series of subobjectives:

a. Evaluate new and existing methods through laboratory studies and literature searches.

b. Identify the methods that appear to be efficacious and environmentally acceptable.

c. Identify those methods that can be used in integrated pest management schemes.

d. Identify, through field studies, environmentally acceptable methods of control for each locality and weed species.

e. Communicate knowledge gained and its practical application to personnel involved in weed control.

Although EPA certifies certain herbicides as safe for specific aquatic uses through its pesticide registration activities, more work needs to be done that relates weed control practices to environmental quality. It is clearly time to do so because, for example, new formulations of controlled-release herbicides are under development, and the sterile hybrid of the white amur (grass carp) and bighead carp are being considered possibly for wide usage. By testing environmental impacts of weed control measures, EPA can aid its own regulatory function by recommending specific measures for specific problems.

Information Gaps

The EPA program will address some of the major information gaps in research on aquatic weed control, such as why plants occur as weeds in some areas but not in others. Little is known about their basic biology, and research needs to be done in that area. Also, if more is known about their basic biology, perhaps specific control measures could be developed for each species.

Another major problem is related to long-term control. We need to find methods that will inhibit rapid reestablishment of plants. Perhaps integrated control will be best here in order to avoid chronic effects of chemicals on nontarget species. Controlled-release herbicides may also be of great importance for long-term control.

Biological control methods, such as plant pathogens and phytophagous fishes, may be studied in-depth because, if developed, such methods may obviate the need for extensive chemical control.

General Approach

Initially, a substantial amount of the EPA program will be carried

out by other Federal agencies, but support will be given to research projects of individuals in universities or in State regulatory and control agencies. Projects funded will cover the areas of chemical, biological, mechanical, and integrated control. All, except basic research, will provide data with regard to environmental safety. It is expected that, over the next few years, the program will become less broad in scope with emphasis on development of environmentally sound control procedures based on information gained during the program's initial years. It is projected that the EPA program, over the next few years, will place less importance on chemical control and more emphasis on biological and integrated control.

Applications of EPA Research

At present, methods are needed to control weeds safely, efficiently, and economically without harm to (a) sportfishing, boating, or recreational sites; (b) irrigation canals, reservoirs, and ditchbanks without affecting water quality as it relates to drinking and irrigational use; and (c) aesthetics. Knowledge gained from the EPA program will be published and disseminated widely for judicious use of control methods resulting in minimal negative environmental impact in relation to water use.

North Central Division, St. Paul

by

Wayne Koerner*

St. Paul District's Aquatic Plant Control Program serves the states of North Dakota, Minnesota, and Wisconsin. While the District has been involved in the Aquatic Plant Control Program for some time and has attempted to implement it, most of these attempts have failed for lack of local interest. In many cases, the supply of water bodies suitable for recreation or other uses has exceeded the demand to the extent that problem areas could be avoided or ignored.

North Dakota is a "water-poor" state because it has few natural lakes. The lakes are concentrated in the north-central and central portions of the state. Most of the bodies of water in the remainder of the state are reservoirs. Of the approximately 200 lakes in North Dakota with significant recreation use or potential, about 30 have some type of plant overgrowth or accelerated eutrophication.

In addition to improving the state's recreation resources, North Dakota has an additional interest in pursuing the Aquatic Plant Control Program. If North Dakota is to increase its supply of surface water for recreation and other purposes, additional reservoirs are needed. However, some existing reservoirs are experiencing problems before it was expected. Visitor attendance at existing reservoir sites is not as high as expected because of eutrophication or weed conditions. Thus, the reliability of attendance estimates for other planned lake developments is in question.

Wisconsin and Minnesota, on the other hand, have a rich natural resource in their numerous lakes and streams. The inland lakes are most numerous in the glacial outwash areas along the southern edge of the Great Lakes. Numerous lakes, in lesser density, are located throughout both states. The problem most often brought to our attention is with lakes that are experiencing recreation pressure and becoming eutrophic or overgrown with rooted aquatic plants. Blue-green algae (aphonizomi-non) and the submergent rooted aquatics (*Potamogeton, Vallisneria,* and *Ceratophyllum*) are the most typical problem plants in the midwestern States.

With increasing development and pressure for water-based recreation, hunting, and fishing, lakes that had been inaccessible or unusable

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in prior years are now needed to meet the demand. Wisconsin has recognized this problem and the problem of the lakes becoming eutrophic and has instituted State programs to deal with them. The Inland Lakes Renewal Program was established to rehabilitate degraded lakes and, if possible, preserve the conditions of others not yet in danger of infestation.

The St. Paul District's most recent effort in the Aquatic Plant Control Program is a reconnaissance study for Buffalo Lake which is a 2500-acre impoundment on the Upper Fox River in Marquette County, Wisconsin. Buffalo Lake is centrally located in the southern half of the state approximately 50 miles north of Madison, Wisconsin's State capital.

Buffalo Lake was formed in 1871 when the level of a natural basin was increased by 4 ft. The Corps of Engineers constructed a low-head dam and lock structure at the outlet of Buffalo Lake as part of a navigation system connecting the Wisconsin River to Lake Michigan. A canal was constructed across a 2-mile divide at Portage, Wisconsin, completing the project. In 1962 the project was turned over to the State of Wisconsin.

Buffalo Lake is one of over 90 lakes in Marquette County and accounts for almost 50 percent of the county's available surface water area. It has a mean depth of 4.5 ft with a maximum depth of 8 ft. It is about 12 miles long and has a maximum width of 0.5 mile. The lake would make a fine recreation attraction to nearby population centers if the submergent vegetative growth were controlled. Several resorts are along the lake which has about 16 miles of developable shoreline. Out-of-state residents fishing in the region exceed local participants by 4 to 1. If Buffalo Lake were not kept accessible, tourism in the area would suffer dramatically.

Prior to 1970, an overabundance of rough fish, predominantly carp, and wind and wave action combined to decrease water quality and the game fishery. In 1970, a successful rough fish control and restocking project was carried out by the Wisconsin Department of Natural Resources. Since then, excellent, self-sustaining populations of northern pike, largemouth bass, bluegill, perch, and bullhead have been established. However, without the carp disturbing the lake bottom and clouding the water, the native aquatic plant population increased to the point of infesting the entire lake and severely restricting water-based recreational activities.

The species of submerged aquatic plants considered to be a problem in the lake are coontail (*Ceratophyllum demersum*), Canada waterweed (*Elodea canadensis*), curly-leaved pondweed (*Potamogeton crispus*), sago pondweed (*Potamogeton pectinatus*), flatstem pondweed (*Potamogeton zosteriformis*), common naiad (*Najas flexilis*), and wild celery (*Vallisneria americana*). All of the above, with the exception of the unattached mats of coontail, are rooted submerged aquatic plants, are common in other areas, and are natives to the upper midwest (curly-leaved

pondweed was introduced from Europe). Their method of reproduction is mostly vegetative, often by fragmentation of the stem. Wild celery, sago, pondweed, and common naiad are important wildlife and waterfowl plants. In less choking densities, all of these plants are important beneficial members of the aquatic ecosystem. However, the growth rate and conditions in Buffalo Lake are such that, if left uncontrolled, all 2500 acres of the lake will be choked to the water surface with submerged aquatic vegetation.

Since the summer of 1974, the Buffalo Lake Improvement Association has been involved in a mechanical weed harvesting program in an attempt to improve the lake. Five small cutting machines are used to cut the aquatic vegetation. In 1975, the University of Wisconsin Mechanical Engineering Department designed a stationary removal system for floating vegetation which is located upstream of the dam at Montello. The cut aquatic vegetation floats downstream to the removal system where it is loaded onto dump trucks.

These harvesting efforts have been unsatisfactory, in part because of the magnitude of the problem, present technology, and lack of funds. Therefore, the Department of Natural Resources requested, on behalf of the Buffalo Lake Property Owners Association and Marquette County, that the U. S. Army Corps of Engineers perform an aquatic plant control reconnaissance study on Buffalo Lake.

The preliminary plan developed for the reconnaissance study recommends the use of a large mechanical harvester which would be used to maintain approximately 500 acres or about 20 percent of the total lake area. The plan calls for maintaining a channel down each side of the lake with side channels and spot clearing at selected locations. The harvesting would begin in early spring before the problem becomes too great and would continue through the growing season. Preliminary estimates of benefits and costs indicate a favorable benefit-cost ratio.

Public attitudes favor a solution other than the use of herbicides. In addition, a herbicide control plan would probably be less efficient than the recommended method because:

a. Current patterns within the impoundment would make application areas difficult to pinpoint and manage.

b. Drift and dilution of the herbicide could render application ineffective.

c. Heterogeneous plant populations such as those in Buffalo Lake (seven species) may require more than one type of chemical control method to achieve the desired response.

The Buffalo Lake reconnaissance study will be forwarded to higher authority later this year. We hope to learn from the review of this study whether application of the Aquatic Plant Control Program is appropriate for this type of problem.

Inclusion of this type of problem in the program would not

significantly increase our workload even though there are many lakes experiencing similar weed problems. The two main reasons for this are the 30 percent state-provided cost and the historical reluctance of the states to get involved unless the problem has widespread significance in the state.

USAE DIVISION/DISTRICT PRESENTATIONS

AQUATIC PLANT PROBLEMS--OPERATIONS ACTIVITIES

North Pacific Division, Seattle

by

Robert M. Rawson*

The Seattle District is relatively new to the field of aquatic plant control. It has only been in the last few years that we've had a serious problem. Our problem species is Eurasian watermilfoil.

Presently, the problem is restricted to a few areas of the state. Milfoil has not yet caused problems at any Corps of Engineers projects in the state, but could if it continues to spread. The Seattle District became involved in the milfoil problem when the Washington State Department of Ecology requested that we establish a statewide management program. Our proposed management program, which would be on a 70:30 cost share basis, includes the control of existing milfoil problem areas and prevention of further spread.

Our proposed control program would be centered in the Seattle area. Three lakes there, Washington, Sammamish, and Union, are infested. The main impacts to date have been to aesthetics and public recreation. Our objective in these lakes is to eliminate the major obstructions to recreational use without causing an unacceptable impact to the environment. Because of the large number of possible control techniques, and local disputes as to the advantages and disadvantages of each, our approach was to give the maximum amount of flexibility possible to the local sponsor to choose treatment methods for their areas. The alternatives for the Seattle area lakes range from mechanical harvesting to 2,4-D application. In addition, we would approve fiberglass bottom screens, or the chemicals endothall, diquat, and dichlobenil for public swimming beaches. The final choice will be up to the local sponsor.

The other part of our proposed program, the prevention portion, is state-wide in scope but would be initially concentrated in the Okanogan area. British Columbia has had serious milfoil problems for several years and it has moved down the Okanogan lake chain into the U. S. portion of Osoyoos Lake. The British Columbia Ministry of the Environment helped us all they could in slowing down the milfoil spread, but now we have pioneer colonies not only in the lake but also in the Okanogan River. The main objective of our prevention program is to keep the milfoil from becoming established in the Columbia River system.

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Work has been going on for a couple of years in the Okanogan area, paid for mainly by the State Department of Ecology and Okanogan County. We propose to continue and expand their work. The barrier structure which is located on the river just below Osoyoos Lake would be maintained to decrease the number of fragments floating downstream. Also, spot treatments would be done to limit the sources of fragments. The proposed treatment methods for spot treatment are hand removal, 2,4-D, suction dredge, and rotovating. Aerial and ground surveillance would be maintained in these areas and also in the high risk Columbia River reservoirs to identify new colonies for treatment. A public information program will be implemented to reduce the amount of spread caused by recreational boaters and aquarium owners.

A third problem area in the state, the Columbia Basin, is not included in our program. This area is managed by the Bureau of Reclamation and has several irrigation reservoirs and waterways infested with milfoil. This area is not included in our program because it is part of an authorized Federal project and cannot be treated under our authority. Any work done there would have to be funded by Bureau operations and maintenance money. We are very interested in their problems, however, and are working closely with them because of their proximity to the Columbia River and the large source of milfoil fragments.

The main problems remaining are the public opposition due to the inclusion of chemical alternatives and the amount of coordination required among the three levels of government. The way our program is set up, the Washington State Department of Ecology is the umbrella sponsor. They, however, probably will not provide matching funds for local control efforts. Local governments or other potential sponsors must propose the treatment to the Department of Ecology. The Department will then submit a combined State proposal to the Seattle District for funding.

Since our requested funding was cut for FY 80, some priorities of treatment may be required. Our first commitment would be to continue the funding for research by WES. Our second priority would be the program to prevent the spread of milfoil into uninfested waters. The third priority would be the treatment of public recreation areas, and the final priority would be the treatment of high-use public waters which do not front public recreation areas. Within those last two categories, which make up the control program, further prioritization may be required. This would be done jointly by the state and local sponsors.

USAE DIVISION/DISTRICT PRESENTATIONS

AQUATIC PLANT PROBLEMS--OPERATIONS ACTIVITIES

South Atlantic Division

by

Julian J. Raynes*

It is believed that the waterhyacinth was imported from South America about 1884. According to popular belief, this beautiful plant with its lovely lavender flower was given away to visitors at the World Exposition held in New Orleans, Louisiana. The story is that someone near Palatka, Florida, had placed the hyacinth in a tub and that when the plants had multiplied sufficiently to fill the tub, the tub was emptied into the St. Johns River.

In 1896, a Mr. Creel from Palatka, Florida, petitioned the Congress for assistance with the waterhyacinth problem in the St. Johns River. The hyacinth was creating havoc with navigation, often pushing the river boats out of the channel whenever the winds shifted. Oftentimes, fishermen were trapped by rafts of hyacinths and held stranded until the rafts were broken up by river currents or the winds. Similar occurrences in the rivers and bayous of Louisiana also resulted in petitions to Congress for assistance.

The Corps of Engineers Office in St. Augustine, Florida, made a number of reports on the problem and even had the Department of Agriculture make a botanical report on the hyacinth.

In 1899, the River and Harbors Bill authorized the Corps to remove aquatic growths which presented an obstruction to navigation in Florida and Louisiana. It was later modified to include Alabama, Mississippi, and Texas.

Congress, recognizing that 2,4-D herbicide might eliminate the waterhyacinth, enacted the 1958 River and Harbors Act which authorized the expanded Aquatic Plant Control Program. This act authorized control to extend into the rivers, streams, and other waters allied to navigation. It also recognized that the program was also to be conducted in the combined interest of navigation, flood control, drainage, agriculture, fish and wildlife conservation, public health, and related purposes including continued research for development of the most effective and economical control measures within the South Atlantic and Gulf Coastal regions with the Corps providing 70 percent and the states 30 percent.

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In 1965, Congress extended the program to the entire 50 states of the United States. It should be noted that about that time the total program was about $800,000 to $900,000. Today its about three to four times that much and the need is growing.

The Wilmington District, which covers North Carolina, does not have an active control program at this time. The state has requested the Wilmington District to withhold field operations. It does not provide the funding for any cost-sharing operations. However, the District does maintain a very limited amount of field surveillance.

It is interesting to note that Currituck Sound which had about 70,000-80,000 acres of Eurasian watermilfoil was under study by Dr. Graham Davis of East Carolina University under the Sea Grant program during 1977 and 1978. His studies seem to indicate a correlation between turbidities created by meteorological conditions and biomass reductions.

The decline of submerged aquatic plants in the Chesapeake Bay, reported in 1975 and in 1979, apparently has stimulated more research under the Sea Grant Program in its effort to determine what is causing the decline. Dr. Robert J. Orth of the Virginia Marine Science Institute is performing the study under this grant.

In South Carolina, the Charleston District has been maintaining a surveillance program on the alligatorweed problem. Field operations on alligatorweed were halted several years ago because alligatorweed was not listed on the 2,4-D label for use in slow-moving waters. This has been cleared up by EPA Region IV in its interpretation that 2,4-D DMA could be used against alligatorweed in similar amounts as used for waterhyacinth control, i.e. 2 to 4 lb/acre.

The Charleston District is now being faced with a new problem plant, common reed (*Phragmitis communis*). It was first identified in South Carolina in 1961 even though it is widespread in this country. Due to the wide variety of habitats invaded by common reed, from saline to fresh and from standing water to nearly dry sites, it may pose serious problems for most of South Carolina marshes. Charleston is currently preparing a reconnaissance type report on the extent and seriousness of this problem plant for submission to OCE. We anticipate that Charleston will also prepare a problem statement for inclusion in the Corps' research program if approved.

Another problem, reported by the Georgia Game and Fish authorities, involves a filamentous blue-green algae called *Lyngbya*. It was stated that in areas of high nutrient input, tremendous blooms can occur that may render the infested waters useless. About 400 acres of the Lake Blackshear reservoir has been affected. Over 20 acres in Lake Worth and 200 acres in Lake Seminole (a Corps impoundment) were also reported. The state reported that several repeat applications of aquazine were made in small areas last summer with limited success. We hope to have more on this problem later. I feel that the Charleston program will become involved in some form of algae control in the future.

USAE DIVISION/DISTRICT PRESENTATIONS

AQUATIC PLANT PROBLEMS--OPERATIONS ACTIVITIES

South Atlantic Division, Jacksonville

by

James T. McGehee* and Joseph C. Joyce**

Introduction

The Jacksonville District Corps of Engineers in cooperation with the State of Florida, Department of Natural Resources (DNR), conducts aquatic plant control operations under two separate authorizations, i.e. the Rivers and Harbors Act of 3 March 1899 and Public Law 89-298, dated 27 October 1965. Historically, this program has attempted to maintain an acceptable level of control on those aquatic plant species that exhibit a major economic impact on a regional basis. The aquatic plants which fell into this category were waterhyacinth, water lettuce, alligatorweed, and hydrilla. This approach was dictated by (a) the limited funds that have been allocated to the program in past years, and (b) the apparent lack of significant problems associated with other aquatic species in water bodies under the Corps' program.

Program Authorization

After receiving numerous requests for the treatment of minor aquatic plant species from the general public and the agencies conducting control operations under the Corps-DNR aquatic plant control program, it became obvious that the problems being caused by these species were collectively greater than anticipated and were impacting upon the public benefits previously derived from the treatment of the major problem species. Additionally, other exotic plants which have shown the potential of creating serious problems were being introduced and the existing control program was not authorized to attack these species upon discovery. Thus, on 13 September 1978, authority to include these additional species into the control program was requested from the Office, Chief of Engineers (OCE), in Washington, D. C. In this request,

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it was noted that House Document 251, 89th U. S. Congress, 1st Session (the report which justified Public Law 89-298), stated that during an ongoing aquatic plant control program "other obnoxious aquatic plants will require control to prevent invasion into areas cleared of hyacinth and alligatorweed, if full benefit of the control programs on these two plants is to be realized." It was also recognized in this document that a "real need for general legislation authorizing the Secretary of the Army to take early action to bring under control serious infestations of obnoxious aquatic plants of any type, whenever and wherever they may occur," existed. In a letter dated 15 December 1978, OCE granted approval to the Jacksonville District for such treatments on a case-by-case basis; however, approval of each such treatment was to be made by OCE.

Prior to initiation of this program, it was determined that the treatment of these additional species was not a significant departure from the overall program of the Environmental Protection Agency. Thus, on 27 April 1979, an Environmental Assessment was prepared in compliance with the National Environmental Policy Act of 1972.

Justification Procedure

In order for a given problem species to be included in the control program, the following information must be provided to the Jacksonville District aquatic plant control personnel:

a. Name and major watershed where plant is located.

b. Location including a map of the specific area of infestation and the specific area to be treated.

c. Species scientific and common name.

d. The principal uses of the water body in priority order.

e. The magnitude of the infestation (area) and the number of acres to be controlled.

f. The method of control, i.e. mechanical, chemical, or biological.

g. If herbicidal control is selected, the name of the herbicide, the active ingredient rate and application, and the frequency of treatment.

h. Estimated cost of control.

i. A brief statement of the nature of the physical and economic damages caused by plant.

Once this information is received, the District staff will review the request and, depending upon the nature of the request, an onsite inspection may or may not be required. After a determination is made,

control operations can commence upon receipt of notification by the State.

Results to Date

Since receiving approval to include these additional species in the program, 28 requests (Table 1) have been received for the treatment of 18 different species in 21 separate water bodies. Of these 28 requests, 18 were approved, 4 were disapproved, and 6 were approved if an alternate herbicide was used. The approved treatments involved 831 acres of plants at an estimated cost of $113,871 or 2.2 percent of the overall Corps-DNR control program. The average approval time for the requests received was 31 days.

Conclusions

In conclusion, it is felt that this minor expansion in the Corps-DNR program filled a critical gap in the overall management of aquatic plants and provided a substantial increase in the quality and quantity of benefits to the public at a minor cost.

Table 1

Minor Problem Aquatic Plant Control Program

Fiscal Year 1979

Species	Water Body	Acreage	Estimated Costs
Myriophyllum heterophyllum	E. Lake Toho	20	5,000
	Alligator Lake	12	3,125
	Lake Lizzie	12	3,125
Myriophyllum pinnatum	Lake Stone	50	5,731
	Bear Lake	25	3,540
Egeria	Lake Harris	5	1,500
	Suwannee-Santa Fe	15	2,403
	Lake Yale	5	1,500
Leman and *Salvinia*	Julington Creek	7	210
Cabomba sp.	E. Lake Toho	20	5,000
	Alligator Lake	13	3,125
	Lake Lizzie	13	3,125
	Suwannee-Sante Fe	15	2,403
Potamogeton spp.	Lake Marion	100	10,000
	Lake Eva	40	4,000
	Winter Park Lake	15	12,094
*Limnophila sessi flora**	Lake Pierce	4	640
	Lake Weohyakapa	4	640
	Dead Lake	1	1,000
Ceratophyllum demersum	Caloosahatchee River	8	1,132
Alternanthera philoxeroides	Caloosahatchee River	7	1,132
	Lake Tarpon	10	1,188
	Withlacoochee River	90	7,822
Nupkor luteum	Caloosahatchee River	8	1,132
Nelumbo lutea	Lake Jackson**	25	700
Nymphaea odorata	Lake Iamonia**	100	2,800
	Lake Miccosukke**	100	2,800
Hydrocotyle	Caloosahatchee River	7	1,132
Spriogyra algae	Winter Park Lake	100	25,872
Panicum repens	Lake Tarpon	25†	885
Panicum hemitomon	Withlacoochee River	120†	9,548

* Eradication efforts for new infestations.
** Mechanical control.
† Disapproved.

USAE DIVISION/DISTRICT PRESENTATIONS

AQUATIC PLANT PROBLEMS--OPERATIONS ACTIVITIES

South Atlantic Division, Mobile

by

Douglas H. Powell* and R. Douglas Nester**

The State of Alabama, Department of Conservation, coordinated and funded in part by the Mobile District, conducted a comprehensive aquatic plant survey of the Mobile Bay Delta. The survey covered those waters from the Tombigbee River below Coffeeville Lock and Dam and the Alabama River below Miller's Ferry Lock and Dam, through the waterways and bays of the Mobile Delta, to several of the major tidal streams in the upper Mobile Bay area. The survey was initiated in August of 1979 and, due to Hurricane Frederic, was completed in mid-October 1979. Major aquatic plant species were identified and noted with regard to their relative abundance. Approximate acreage or percent infestation of obnoxious plant species was also recorded in areas where serious infestations were found.

The survey team did not locate any infestations of *Hydrilla verticillata* Royle in the Mobile Delta or major river systems below the known infestation in Coffeeville Reservoir on the Tombigbee River. This aquatic plant has probably not had sufficient time to establish in any of these areas. However, further surveilliance of the Mobile Delta below the known infestation will be necessary to monitor this aquatic threat. The infestation in Coffeeville Reservoir presents a serious threat to the entire Mobile Delta.

No serious infestations of aquatic plants were found in the upper regions of the survey area. The number and relative abundance of aquatic plant species increased as the survey progressed southward throughout the Delta. The marginal plants *Zizaniopsis miliacea* (Michx.) Doell and Asch., giant cutgrass, and *Zizania aquatica* L., wild rice, were abundant in numerous areas of the Delta but did not present problems. The colonies of these plants were confined to the shallow or shoreline areas and did not interfere with navigation or water flow. Several other species of aquatic plants were abundant in certain localities, but none presented any problems to navigation or water flow.

Serious problems with obnoxious aquatic plants did not become evident until the lower portion of the Mobile Delta and several arms of

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* Game and Fish Division, Alabama Department of Conservation and Natural Resources, Marion, Alabama.
** U. S. Army Engineer District, Mobile; Mobile, Alabama.

the Basin Negro were reached. Brazilian elodea or anacharis was abundant enough to cause problems in Six Bits Creek, Smith Bayou, Duck Bayou, and Squirrel Bayou. All these waterways are located off the main body of the Basin Negro. Significant infestations of Brazilian elodea or anacharis made navigation by a small outboard powered boat very difficult. The percentage infestations of Brazilian elodea or anacharis found in these locations were from 40 to 60 percent.

Eurasian watermilfoil is a serious problem in several bays and waterways of the lower Mobile Delta. A total of over 2600 acres are presently heavily infested. The majority of these heavily infested areas were completely lacking in navigability, except by airboat. Eurasian watermilfoil was the predominant submersed plant species found in the lower Delta. The amount of the Eurasian milfoil will continue to increase and replace the existing aquatic plant species now in the Delta unless a plant management program is enacted soon. Major infestations are as follows: Bay Minette, 288 acres (60 percent); Bay Minette Basin, 204 acres (85 percent); Chocalata Bay, 995 acres (55 percent); and Delvon Bay, 469 acres (55 percent).

A vast and complex aquatic community is found in the Mobile Delta. Many different plant species were encountered as the survey team travelled southward from the upper reaches of the Mobile Delta; these species were grouped as follows: 2 species floating plants, 32 species shoreline or emersed plants, and 17 submersed plant species.

Currently, the State of Alabama has no approved statewide aquatic plant control program. The Mobile District, State of Alabama, Dept. of Conservation, and a local environmental consultant are presently engaged in the development of such a control program. This program, as planned, will provide for the control of obnoxious plant growth by means of chemical spraying and a suitable monitoring effort to document the adverse and beneficial effects of the treatment on the Mobile Delta ecosystem.

USAE DIVISION/DISTRICT PRESENTATIONS

AQUATIC PLANT PROBLEMS--OPERATIONS ACTIVITIES

South Atlantic Division, Mobile, Lake Seminole Reservoir

by

Joe Kight*

Lake Seminole is a 22-year-old, 37,500-acre reservoir on the Georgia-Florida-Alabama border. It is fed by the Flint and Chattahoochee Rivers, Spring Creek, and Fish Pond Drain. There are four rather separate areas of the lake: Chattahoochee River with the heaviest silt load; Flint River, less silt load and high nutrients; Spring Creek, spring fed and high in carbonates; and Fish Pond Drain, clear water fed from old seepage ponds.

Many species of aquatic plants were present in lime sink ponds that were flooded when the lake was impounded. In addition, some 10,000 acres of trees were left uncleared. This provided cover for fish and wildlife and also made excellent habitat for the production of aquatic plants. I might point out that most of our problem plants are exotics.

Waterhyacinths were first noted on the Flint River arm of the lake in the spring of 1955. This was treated with 2,4-D from boats, which resulted in good control. Very little follow-up work was done until the summer of 1958. At this time, it was estimated that 1200 acres of hyacinths were on the Flint River arm and that they were coming downstream from hydroelectric impoundments.

Two contracts were let, one in July and one in September of 1958. Helicopters sprayed the hyacinths with 2,4-D, again with good results, over some 3000 acres.

Following the hyacinth control program, alligatorweed (*Alternanthera philoxeroides*) became established. Again, the source of infestation was upstream impoundments. The weed was first noted in the summer of 1960 and its spread was very rapid. Waterhyacinths were apparently unable to successfully compete with alligatorweed and were somewhat held in check. Research work by the U. S. Department of Agriculture (USDA) Research Service, supported by the Corps of Engineers, was under way. Biological control was the subject of the study. The potential use of manatees and snails, as well as plant pathogens, was studied; however, most of the biological control research was devoted to arthropods, principally insects.

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* Lake Seminole Resource Managers Office, U. S. Army Engineer District, Mobile; Chattahoochee, Florida.

The alligatorweed flea beetle, *Agasicles hygrophila*, was selected for introduction after extensive studies. This beetle is in the family Chrysomelidae, order Coleoptera. It is host specific. The first release involved approximately 800 flea beetles at two sites about 5 miles apart on the Chattahoochee River arm in 1966. Although the beetles became established, they never developed large populations. The second release of 100 beetles was in May and July 1967 on the Flint River arm. By November they had increased in numbers and had spread about 15 miles upstream from the release site. By October 1968, they were well established and were causing considerable damage. By August 1969, reduction of vegetation was estimated at 77 percent.

By the end of 1970, only patches of marginally rooted alligatorweed that showed beetle damage remained. At the start of the program, alligatorweed mats averaged 28 ft wide. *Agasicles* activity reduced these mats by 97 percent over a 4-year period. Alligatorweed is not now considered a problem at Lake Seminole. However, with the reduction of alligatorweed, waterhyacinths reacted quickly to fill the niche.

We used wooden spray boats and aluminum skiff boats and were only able to contain the mats. We finally got an air boat and were able to do a better job.

The hyacinths got ahead of us again and another helicopter contract in the summer of 1978 slowed them down. The helicopter operated off a barge, the barge being under way most all the time. This was the least expensive way to treat hyacinths. Total cost was a little over $7.00 per acre, approximately $1.00 less than the air boat. The rental rate was rather steep--$225.00 per hour--but operating from the barge practically eliminated dead-heading or ferrying time. The helicopter operator started spraying hyacinths just about as soon as he was airborne. This was followed up with spot treatment by a fixed wing aircraft approximately a month later. Right now, we are ahead again.

Eurasian watermilfoil, *Myriophyllum spicatum*, was first noted in the Spring Creek arm of the lake in 1965. This rapidly expanded to 2000 acres in 1972, 4500 acres in 1973, 5000 acres in 1974, and peaked out at 8000 acres in 1975. It has somewhat stabilized at this acreage. This is probably due to the plant having filled the available habitat in the lake--either having established itself or is unable to compete with other plant species. It doesn't seem to grow at water depths much greater than about 12 ft.

In the summer of 1976, 18,000 lb of Aquakleen, a pelletized form of 2,4-D, was applied at a rate of 100 lb/acre of material which equates to 20 lb active ingredient per acre. An additional 20,000 lb was applied to 200 acres in the summer of 1977. The treatment was effective, but the treated areas have again become invaded and the plant is reestablished.

Hydrilla, *Hydrilla verticillata*, was first noted in the lake in 1968. This was a small patch adjacent to a boat ramp. By the summer of 1973, the infestation had expanded to 5 acres and we began to work

on it. Three different plots were treated with the equivalent of 200 lb of Hydout per acre; 10 gal of Komeen per acre, and a combination of 4 gal of K-Lox with 2 gal of diquat per acre.

In 1975 there was an estimated 800 acres of hydrilla, of which 80 acres was treated. The areas treated were high use areas and we knew that all we were doing was chemically mowing the weeds, that they would come back, but at least the people could use the areas for boating, skiing, swimming, and other water activities.

Later, we hired an Emair airplane, an agricultural airplane built in Texas. It had a 1200-hp engine and could haul all the material we could put into its hopper. Our crew loaded the chemical from the storage building into a hydraulic-operated, truck-mounted hopper. The truck then drove down the ramp to the airplane and loaded the plane. While the pilot was applying the material, our crew would be loading the truck hopper. The loaded plane would take off, apply the material to the site, be back on the ground and loaded again in less than 10 min.

Coverage was excellent. Total cost of the truck and driver and airplane and pilot totaled out to $1.98/lb or $4.45/acre. Our labor and equipment cost another $1.00/acre for a grand total of $5.45/acre.

In 1976 there was an estimated 1200 acres of hydrilla; 90 acres in the high use areas was treated. In 1977 there was 2000 acres; 180 acres was treated. The annual plant survey for 1978 indicated that there was some 2500 acres of hydrilla. Today, I would guess that there is probably close to 3500 acres.

We've tried Komeen, K-Lox, diquat, cutrine, Hydrothol, Aquathol-K, Hydout, Aquakleen, and Banvel with dicamba. Most of these, excepting the 2,4-D formulations, will more or less mow the plant to where the recreating public can use the area. None, however, has prevented the plant from coming back, presumably from the tubers. We use Hydout because of its ease, speed, and low cost of application.

An interesting phenomenon occurred on one area. Dr. John Gallager, who is with Union Carbide, is working with us experimenting with fenac. Part of a cove in Rays Lake, which is a 235-acre lake connected to Lake Seminole by a narrow channel, was treated. This cove contained 5 surface acres or 50 acre-feet of water, and was treated with fenac at a rate of 2 ppm. This was on 26 April 1979. The entire 235 acres was infested with hydrilla with scattered patches of pondweed (*Potomogeton illinoensis*). On 9 July 1979 the hydrilla in the entire area was covered with a dark brown crusty substance. Condition of the plants was deteriorating. By 20 August the hydrilla was gone, both inside the plot and over the entire 235 acres. A very few scattered individual stems of pondweed could be found, perhaps 10 percent of what was present at the time of treatment.

The one thing that had happened to the area that we know about was the inflow of water that was high in tannins. There was a series of beaver dams, perhaps a dozen, at the headwaters of the lake. A

survey crew was remarking a boundary line which ran through the beaver ponds. They broke a number of dams and partially drained the area. The water in Rays Lake took on a brown, "swamp water" appearance.

Dr. Gallagher said that he wished that the fenac could take credit for this effect, but that it could not. After careful analysis of the situation and much discussion, it was generally agreed that "God done it." Samples of hydrilla from within, on the fringe, and outside the affected area have been collected and delivered to the USDA Biocontrol Laboratory in Gainesville. They have not had time to analyze the samples. Needless to say, we are all keeping our fingers crossed.

To date, hydrilla has increased from a few sprigs to approximately 3500 acres. It has disappeared from 235 acres, but we don't know why.

Giant cutgrass (*Zizaniopsis miliaceae*) is a little bit different. It just keeps spreading. From an estimated 3 acres in 1960, we have approximately 5700 acres now. It seems to spread only by vegetative means. We know that a stalk of it will fall over and send out roots and leaves from each node. This can and often does represent a 5-ft lateral spread each time a stalk falls over.

Giant cutgrass is an excellent silt trap. It can form a barrier across the mouth of shallow coves (it can grow in water up to about 4 ft deep). Silt and debris soon form a bar which prevents the exchange of water. Then eutrophication really begins.

The big problem with cutgrass is that it literally builds land. Of our 5700 acres of cutgrass, probably 5000 acres of it is on dry land--land that used to be water. This is creating problems on the Chattahoochee River arm. The main river channel is rather sinuous with assorted shallow sloughs on either side. The Chattahoochee carries a rather high silt load during high water in the spring. The river would flood these areas and deposit most of the gravel, sand, and silt in these backwater areas. Cutgrass has, in effect, built dikes on each side of the river on top of the natural river levees. This tends to keep the silt load in the river channel until it gets to the lake proper.

We have used dowpon, 2,4-D, and banvel 720 with dicambia on the cutgrass. None of these chemicals were very effective.

Dr. Larry Hawf obtained an experimental use permit and some Roundup; three plots were treated with 1, 2, and 3 gal of Roundup. Application was made with a handgun with a single 8010 nozzle tip on 20 June 1978. Application was made to runoff with an estimated total volume of 80 to 100 gal/acre. This figures out on paper to 2, 4, and 6 gal of Roundup per acre. Checks of the plots on 26 September 1978 indicated control at 97 percent on the 1-gal plot, 98 percent on the 2-gal plot, and 94 percent on the 3-gal plot.

Checks on 21 June 1979 indicated 70 percent control on the 1-gal plot, 85 percent on the 2-gal plot, and 75 percent on the 3-gal plot.

It is felt that most of this growth resulted from fragmented plants washed ashore from other stands.

On 21 June 1979, application was made to three plots with a solo backpack mistblower. Application rate was 1/2 gal/acre, 2.25 lb or 3/4 gal/acre, and 3.0 lb or 1 gal/acre. Percent control as of 20 September 1979 was 60, 60, and 70, respectively. This is the 1-gal/acre plot.

As you can see, Roundup was quite effective in controlling cutgrass. If a water label is obtained, I think we can stop further encroachment of giant cutgrass.

We've tried mechanical means of plant removal. This will work until the wind blows them back in. We've tried cutting them and loading them in the water. This didn't work either. We've tried mowing them and leaving them in the water. We've tried mowing them on the hill. As a point of interest giant cutgrass will produce 16 in. of new growth in 10 days. We've tried digging them up by the roots. A machine, called a cookie cutter, would cut down to a depth of about 18 in., which was great for deepening the shoreline. It would remove weeds, muck, mud, sand, etc.; it would not, however, remove lightered pine stumps.

Of all the biological controls, weevils, moths, a stray cow or two, only the *Agasicles* flea beetle is a success. Hopefully, the hydrilla is under attack by some organism that will at least control the stuff.

Of the mechanical means, anything smaller than 1-1/2-yd drag bucket is rather marginal.

Of the herbicides, we know that 2,4-*D* will economically control hyacinths and Eurasian watermilfoil. Roundup will control cutgrass and will be a viable solution if it is cleared for use in water. A number of herbicides will effectively mow hydrilla. We use Hydout for the reasons already mentioned.

In conclusion, we feel confident that new products will be developed to control our problem weeds. We are also confident that when one weed is controlled, three or four more will take its place.

USAE DIVISION/DISTRICT PRESENTATIONS

AQUATIC PLANT PROBLEMS--OPERATIONS ACTIVITIES

South Atlantic Division, Savannah

by

Herbert T. DeRigo*

The establishment of a cooperative aquatic plant control program between the Savannah District, Corps of Engineers, and the State of Georgia has not been easy. District records show that a contract for the control and eradication of obnoxious plant growth was in effect as early as 1965 and amended in 1970. However, up to the present time, no work has been done by the State under this contract.

The reason for the lack of interest in the aquatic plant control program by the State was the fact that the aquatic plant infestations in the main rivers and tributaries of Georgia, at that time, contributed no major problems to the objectives of the control program. I released the alligatorweed flea beetles (*Agasicles*) on the Savannah River and Satilla River in the mid-1960's while employed by the U. S. Department of Agriculture. At that time I was doing some research on the physiology of alligatorweed.

In 1968 when I became employed by the Savannah District, I prepared the General Design Memorandum for Georgia, outlining a comprehensive program for aquatic plant control.

In the past 2 to 3 years, the State of Georgia began to show some interest in the aquatic plant control program. It appeared that the State was receiving pressure from the public to control aquatic growth in public places; however, the State did not have the funds to do an adequate job. A meeting was held with the Fish and Game Division of Georgia Department of Natural Resources (DNR) in which the State expressed an interest in the aquatic plant control program. The Savannah District proceeded then to prepare and process an environmental impact statement (EIS) for the aquatic plant control for the State of Georgia. The final EIS was filed in August 1979. Another meeting was held with the Georgia DNR in September 1979. Mr. Joe Joyce from the Jacksonville District was present at that meeting to answer operational questions posed by the State. Savannah District will model its program after Jacksonville. The State was not clear as to the extent and purposes for aquatic plant control in Georgia water bodies. We referred to the authorization, pointing out the various purposes, but also noting that areas of major significant impact must be affected.

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* U. S. Army Engineer District, Savannah; Savannah, Georgia.

The Savannah District is currently adapting Jacksonville District's computer program and contract. We will have to reach an agreement on the contract and format of the weekly worksheet. Also an environmental assessment will be prepared to allow for the use of other EPA-approved herbicides besides 2,4-D. When these last few items of agreement are cleared, we expect to be cost-sharing with the State shortly. The program is envisioned to represent an initial $42,000 effort for FY 80, but is expected to expand as the program develops. A particular problem in the State is the algae *Lyngbya*. We expect to work with WES on this situation.

USAE DIVISION/DISTRICT PRESENTATIONS

AQUATIC PLANT PROBLEMS--OPERATIONS ACTIVITIES

South Pacific Division

by

Harry W. Dotson*

Introduction

We have been considerably more fortunate than some of the other Divisions, especially those in the Southeast, in that our problems with aquatic weeds have been fairly limited. There has been no evidence to date that current problems within the South Pacific Division (SPD) are of major economic significance or significantly affect Federal facilities. It is obvious that having only minimal problems has led to the relatively minor role SPD has played in the Corps' Aquatic Weed Control Research Program. However, I would like to share information concerning current conditions in SPD with you so that you can better understand what the aquatic weed control program in SPD involves.

Area Problems

In the San Joaquin River Delta, there has been a recurring problem in the last several years with waterhyacinth. This area is located about 60 miles northeast of San Francisco. The San Francisco-San Joaquin Delta contains about 1000 miles of channels and sloughs and is used extensively by recreational boaters. The waterhyacinth has created a nuisance to recreational boaters in isolated areas and has troubled some resort marina operators in the area. The problem has not affected commercial navigation, flood control, or Federal facilities other than minor instances when the weed has caused problems at the Water and Power Resources Service pumping plant near Tracy, California. This plant pumps water to the Delta Mendota Canal which supplies water to Southern California. The Sacramento District has received several requests from recreation marina operators for assistance in controlling the problem. The District is now planning to study the current situation to determine if there is a Federal interest. If remedial actions show economic justification, a project will be recommended under the aquatic weed control program authority.

* U. S. Army Engineer Division, South Pacific; San Francisco, California.

In Marysville, California, there has been a relatively moderate problem with hydrilla in Lake Ellis. Lake Ellis is a small, fairly shallow lake that was constructed by the WPA in the 1920's. Local interests have requested assistance, but a Federal interest is not evident. Local interests have expressed some concern that the weed could spread into nearby irrigated rice fields and cause significant problems, but there has been no evidence of this to date. The State is currently looking into assisting the City of Marysville in alleviating the problem at Lake Ellis.

In San Gabriel River Basin, there has been a moderate problem with alligatorweed in the San Gabriel River Corps flood control channel. The channel is located in the northeastern suburbs of Los Angeles. The soft-bottom flood control channel is used for groundwater recharge. A good portion of the water used for recharge is sanitary treatment plant effluent which contributes significantly to a favorable environment for alligatorweed. At the present time, the Los Angeles District finances a spraying program carried out by the Los Angeles County Agricultural Commission. The latest situation is that the problem is about 80 percent under control.

In the Imperial Valley, there has been an intermittant problem with hydrilla in non-Federal irrigation channels and ditches approximately 100 miles east of San Diego. Problems here have not been significant and a Federal interest is not evident.

There has been some concern expressed that the moderate infestation of Eurasian watermilfoil that is currently causing problems in the Pacific Northwest, particularly in Lake Washington, will spread south to California. To date, there has been no evidence that this is occurring or will occur. It appears that the problem is relatively site specific depending on factors such as age of the water body, nutrient loadings, and water surface fluctuation. However, I have very limited knowledge about the extent of the infestation of watermilfoil in the Pacific Northwest or how it has progressed. Fortunately, it is evident that conditions in Corps reservoirs in the North Pacific Division and the South Pacific Division have not been suitable for watermilfoil infestation.

Conclusions

In conclusion, based on current authority and since it is not apparent that aquatic weed related problems are creating major economic impacts or significantly affecting Federal facilities in SPD at this time, SPD is not recommending an aquatic weed control program. The Sacramento District will investigate the problem in the San Joaquin Delta and make appropriate recommendations based on that study. The Districts will continue to monitor conditions involving aquatic weed infestations and their associated impact and initiate studies for

recommending remedial measures where it is evident that impacts are or have potential for becoming significant.

USAE DIVISION/DISTRICT PRESENTATIONS

AQUATIC PLANT PROBLEMS--OPERATIONS ACTIVITIES

Southwestern Division, Galveston

by

N. Joyce Johnson*

Introduction

The current aquatic plant control program for the Galveston District consists of the eradication and control of waterhyacinth (*Eichhornia crassipes*) and alligatorweed (*Alternanthera philoxeroides*). Hydrilla (*Hydrilla verticillata*) has become a serious problem in portions of Texas; however, control of this species is not presently authorized as part of the Galveston District's Aquatic Plant Control Program.

The Galveston District program is a cooperative cost-sharing and contractual agreement between the Federal Government and local interests. The Galveston District represents the Federal Government, and the Texas Parks and Wildlife Department represents the State of Texas as the local cooperating agency. Field operations are carried out by the Texas Parks and Wildlife Department under the supervision of Mr. L. V. Guerra, Director, Noxious Vegetation Control Program for the State of Texas.

Eradication and control activities are performed in 18 designated work areas in accordance with mutually established geographical priorities. These areas are oriented to the watersheds of major river basins and coastal drainage systems. Our program is primarily limited to activities in the lower portions of the following 10 work areas (Figure 1):

a. Nueces River Basin

b. Guadalupe River Basin

c. North Coastal Area

d. Sabine River Basin

e. Trinity River Basin

f. Neches River Basin

g. Cypress Creek Basin

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* U. S. Army Engineer District, Galveston; Galveston, Texas.

h. South Coastal Area

i. San Jacinto River Basin

j. Rio Grande Basin

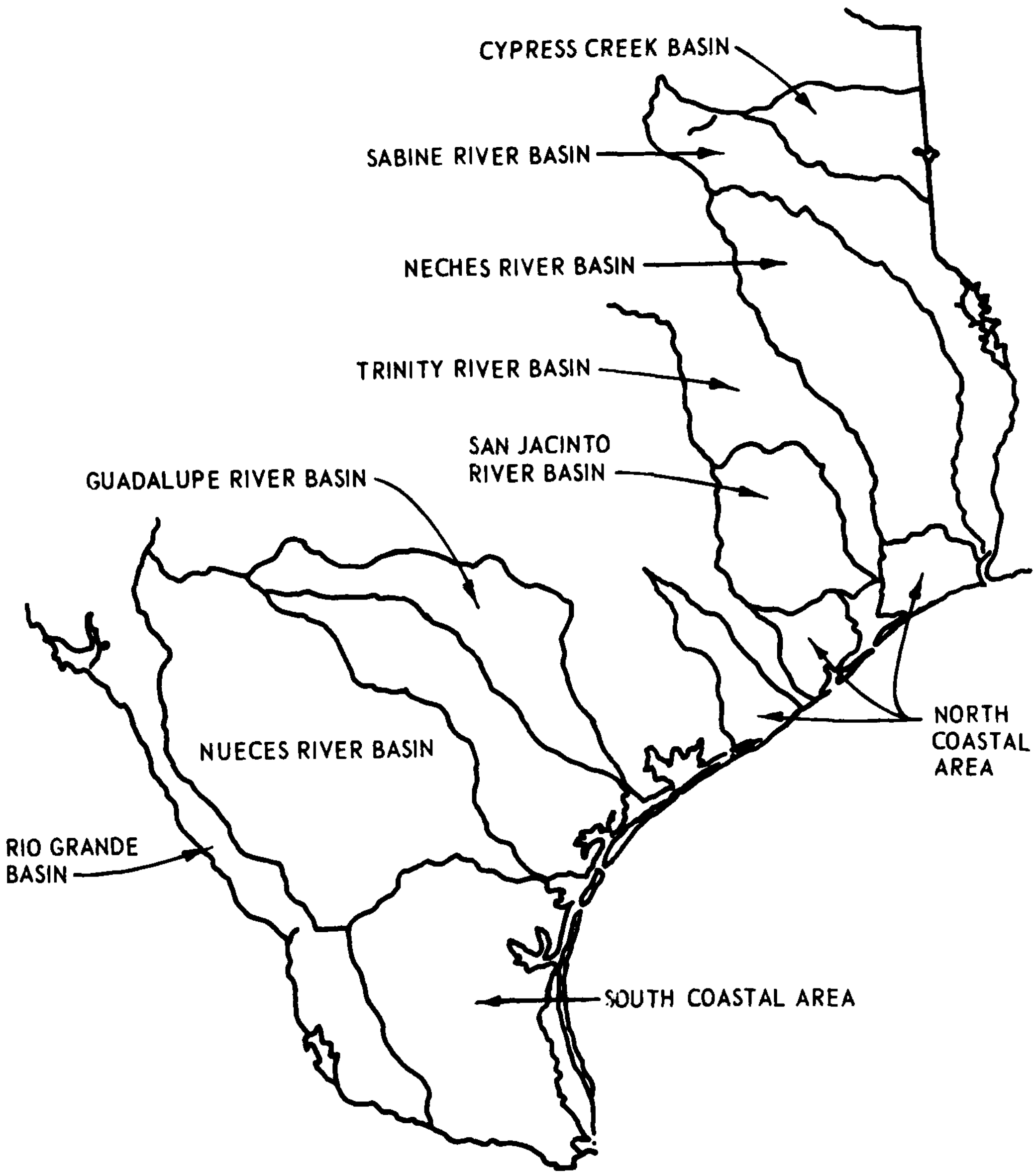

Figure 1. Texas work areas

Status and Control

Waterhyacinth

Waterhyacinth continues to be a serious aquatic plant pest in Texas. A total of 6820 acres (Table 1) of hyacinth were estimated for the 10 work areas in May 1979 compared with 5815 acres reported in June 1978. Control measures for waterhyacinth involve the use of EPA-approved formulations of 2,4-D (Dimethylamine salt of 2,4-Dichlorophenoxyacetic Acid).

Waterhyacinth infestations are presently most critical in the North Coastal Area and Sabine River Basin. The San Jacinto, Trinity, Guadalupe, and Nueces River Basins are also problem areas which require frequent herbicide treatment. Fewer than 100 acres occur in each of the remaining four work areas, but these infestations must be treated periodically to control the spread of hyacinth in these regions.

Aligatorweed

Infestations of alligatorweed have increased in recent years throughout much of southeast Texas (Figure 2). Available information indicates that the species has expanded its range to the southwest and northeast from previous localities.

The estimated acreage of alligatorweed occurring in Texas for 1971 to May 1979 has increased from 8,400 acres in 1971 to approximately 11,410 acres at present (Table 2). The Trinity and Sabine River Basins and North Coastal Area are the most critically infested regions at this time. However, extensive infestations also occur in the Neches and San Jacinto River Basins.

Alligatorweed control methods to date have involved the use of *Agasicles* flea beetles (*Agasicles hygrophilla*).

Hydrilla

Hydrilla was first discovered in Texas in 1970 in the reflection pool of the Houston Zoo. Hydrilla infestations have continued to increase substantially in portions of Texas (Figure 3). Approximately 8000 acres of hydrilla was reported in Texas in 1979, compared with 2900 acres in 1977 and 1200 acres in 1976. The most serious problem presently occurs in Lake Conroe in the San Jacinto River Basin, where 32 percent of the 21,000-acre lake is infested. Estimates of hydrilla infestations reported by location in May 1979 are as follows:

Lake Conroe	6800 acres
Lake Livingston	400 acres
Toledo Bend Reservoir	500 acres
Lewis Reservoir, adjacent to Lake Conroe	200 acres
Raven Lake, Sam Houston State Park	25 acres
San Marcos River	15 acres
South Texas, irrigation ditches	50 acres
Black Creek, near San Antonio	2 acres

Table 1

Estimated Acreages of Waterhyacinth

In Texas (1971-1979)

Work Order	Area or River Basin	1971	1974 Aug	1975 Aug	1976 Jul	1977 Aug	1978 Jun	1979 May
1	Nueces River Basin	200	25	150	50	600	500	500
2	Guadalupe River Basin	2,000	1,000	150	100	100	150	150
3	North Coastal Area	3,000	2,000	300	500	3,000	1,500	2,500
4	Sabine River Basin	5,000	5,000	500	1,000	3,000	3,000	3,000
5	Trinity River Basin	2,450	2,000	2,500	1,000	1,500	300	300
6	Neches River Basin	800	800	500	200	300	100	100
7	Cypress Creek Basin	100	95	100	50	100	30	30
8	South Coastal Area	500	500	75	50	150	25	30
9	San Jacinto River Basin	700	700	2,000	3,000	1,200	200	200
10	Rio Grande Basin	5	5	10	25	50	10	10
	TOTAL ACREAGE	14,755	12,125	6,285	5,975	10,000	5,815	6,820

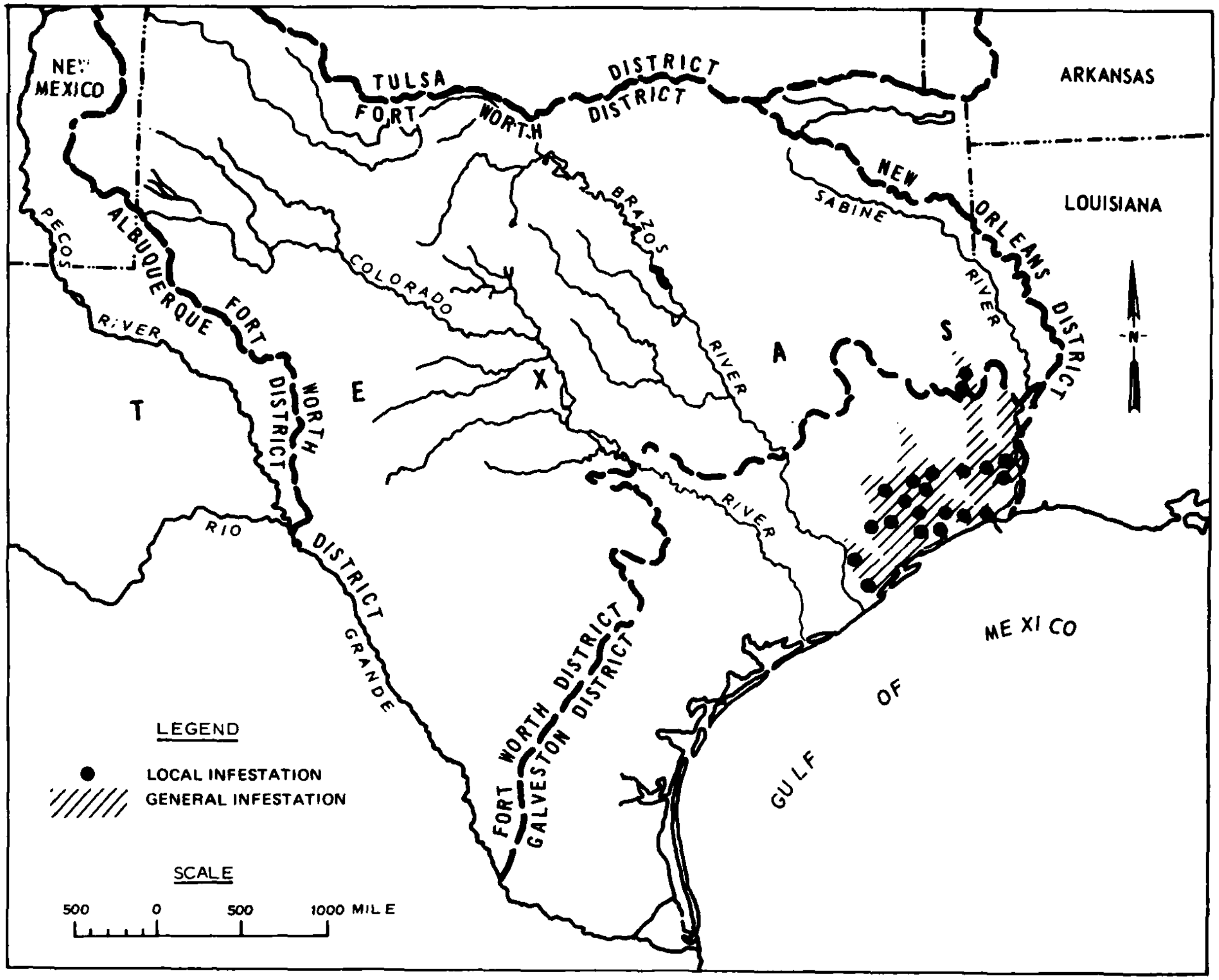

Figure 2. Alligatorweed infestations in Texas

Table 2

Estimated Acreages of Alligatorweed

In Texas (1971-1979)

Work Order	Area or River Basin	1971	1974 Aug	1975 Aug	1976 Jul	1977 Aug	1978 Jun	1979 May
1	Nueces River Basin	--	--	--	--	--	--	--
2	Guadalupe River Basin	--	--	--	--	--	--	--
3	North Coastal Area	2,000	1,800	4,000	4,000	5,000	4,000	4,000
4	Sabine River Basin	1,500	1,500	2,000	3,000	3,000	2,000	2,000
5	Trinity River Basin	3,000	3,000	3,000	6,000	6,000	3,000	3,000
6	Neches River Basin	400	400	750	2,400	3,000	1,200	1,200
7	Cypress Creek Basin	--	--	--	--	--	10	10
8	South Coastal Area	--	--	--	--	--	--	--
9	San Jacinto River	1,500	1,500	1,500	3,000	3,000	1,200	1,200
10	Rio Grande Basin	--	--	--	--	--	--	--
	TOTAL ACREAGE	8,400	8,200	11,250	18,400	20,000	11,410	11,410

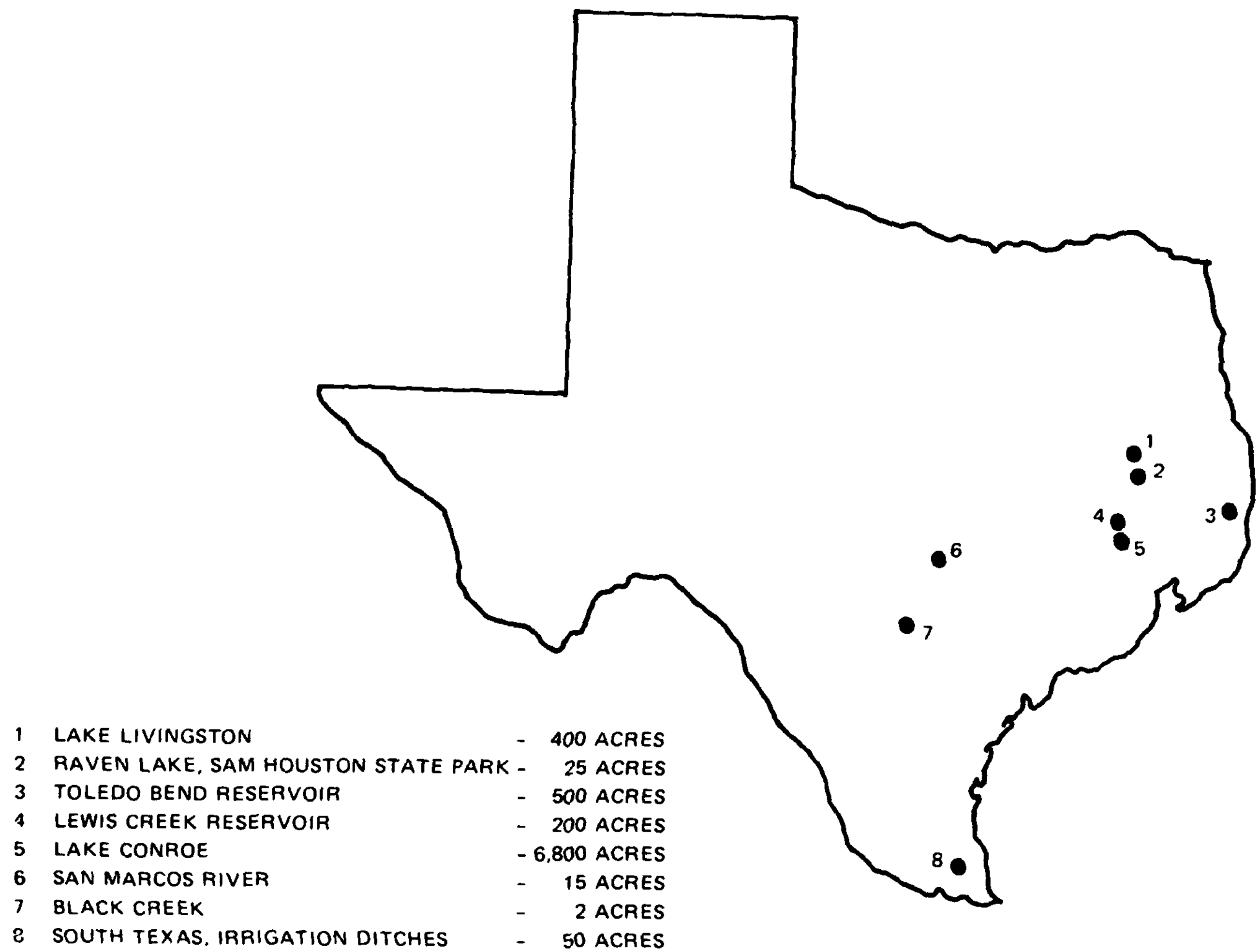

Figure 3. Distribution of hydrilla in Texas, May 1979

Considerable interest has been generated to include hydrilla control as part of Galveston District's Aquatic Plant Control Program. In order to accomplish this task, economic and environmental studies are presently being conducted in order to revise the General Design Memorandum and supplement the Environmental Impact Statement to include control of this species. Treatment to date in Texas has primarily involved experimental control on Lake Conroe and Lake Livingston by the Texas Parks and Wildlife Department.

Considerable problems are expected with the extremely high cost of most of the herbicides being tested. Although the Galveston District is presently under considerable pressure to initiate a hydrilla control program in Texas, the effort is constrained at this time by current technological and personnel limitations. The Galveston District is interested, however, and is exploring all available avenues to accelerate environmental and economic studies necessary to include the control of hydrilla as part of our program. The thrust of these studies is directed toward identifying the effective and economical control methods for hydrilla in Texas.

Summary

The Galveston District administers an active aquatic plant control program for the State of Texas. This is a 70:30 percent cost-sharing program with the Texas Parks and Wildlife Department.

Primary activities currently consist of control of waterhyacinth and alligatorweed in southern and southeastern Texas. Most of this work is performed within 100 miles of the Texas coast.

We are currently performing control operations in 10 Texas work areas. Work orders were issued for the San Jacinto River Basin and Rio Grande Basin during 1977 because of increased problems with noxious plants in these regions, especially in the San Jacinto River Basin. This compares with work in eight areas in 1976, six areas in 1973, and only three areas in 1972.

Waterhyacinth continues to be our biggest problem. Although we consider waterhyacinth to be basically under control, intensive efforts are required annually to effectively control infestations.

Infestations of alligatorweed have increased in recent years throughout much of southeast Texas. Control methods to date have involved the use of *Agasicles* flea beetles, which have only been marginally successful in Texas.

A comprehensive survey of the extent of aquatic week infestations in the Galveston District has not been conducted since 1971. A resurvey of problem areas is needed in order to determine the effectiveness of our present program and to document the spread of certain species.

Considerable efforts will be required in order to incorporate hydrilla control into the existing program. However, the lack of technological information and the present manpower shortage has severely limited the capability of the Galveston District to perform the planning tasks expected to make the necessary changes to its program.

USAE DIVISION/DISTRICT PRESENTATIONS

AQUATIC PLANT PROBLEMS--OPERATIONS ACTIVITIES

Southwestern Division, Tulsa

by

James R. Skaggs, Jr.*

The Tulsa District has three projects with significant infestations of Eurasian watermilfoil (*Myriophyllum spicatum*): Millwood, Pat Mayse, and Robert S. Kerr Lakes. In Tulsa District alone, the range and flexibility of this plant is evident when you compare the characteristics of these three lakes. They are in three separate river basins, three different states, and are quite different in their physical characteristics.

Millwood Lake, located in southwest Arkansas, is a medium size like with 29,500 surface acres and average water quality. Millwood is a swampy lake that is relatively shallow with an average depth of 6 ft. The majority of the lake is covered by dense standing timber. This lake provides an excellent habitat for aquatic plants and has numerous species of floating, submerged, and emergent aquatic plants. Eurasian watermilfoil was first identified in Millwood in 1977 and remote sensing has revealed that there is approximately 200 acres of watermilfoil in the lake. In late summer and early fall, 40 to 50 percent of the surface area is covered by a combination of these aquatic plant species. The Arkansas Fish and Game Commission initiated a drawdown program in 1970 for both fishery and aquatic plant management. However, this program was unsuccessful in controlling the aquatic vegetation. As a result, the Arkansas Fish and Game Commission initiated stocking of white amur (*Stenopharyngodon idella*) in 1977 to control the aquatic vegetation. The Corps will maintain the boat lanes, boat ramps, and marina, if necessary, by utilizing 2,4-Dichlorophenoxyaretic acid, butoxyethanol ester (2,4-D BEE). This would result in an integrated aquatic plant control program of biological and chemical control.

Pat Mayse Lake, located in northeast Texas, is a smaller lake with 6000 surface acres of water. Pat Mayse is deeper than the other two lakes with few shallow areas and has excellent water quality. Eurasian watermilfoil was first observed in this lake in June 1978. There was approximately 50 acres of infestation at that time. Remote sensing conducted in August and November 1978 revealed 150 and 360 acres of watermilfoil, respectively. It was theorized that this rapid expansion resulted from a drastic drawdown of the lake due to drought conditions

* U. S. Army Engineer District, Tulsa; Tulsa, Oklahoma.

which exposed more shallow areas for plant growth. The same pattern was experienced this year with 50 acres or less of watermilfoil in the spring that bloomed to approximately 175 acres in late summer. Several boat ramps and swimming beaches were affected this year. As a result, a control program will be initiated in 1980.

Robert S. Kerr Lake (Lock and Dam 15) is located on the McClellan-Kerr Navigation System in eastern Oklahoma. Kerr is the largest of the three lakes with 42,000 surface acres, and has a considerable amount of shallow mud flat areas and relatively poor water quality. Eurasian watermilfoil was first discovered in the Illinois River arm of the lake in 1972. There was approximately 50 acres of watermilfoil. The infestation expanded and spread throughout the lake until it peaked at approximately 1600 acres in October 1977. At that time the Eurasian watermilfoil was located in almost all areas of the lake with the major concentration located at the mouth of the South Canadian River, the Sandtown Bottom, the Sanbois Islands, and the Illinois River.

A limited control program utilizing 2,4-D BEE was initiated on Robert S. Kerr in June 1977. The program was confined to recreation areas with 65 acres of watermilfoil being treated. In 1978 the control program was expanded to include treatment of 400 acres. However, a regression of the watermilfoil had begun and only 190 acres was actually treated. In 1979, only a minimal spot treatment was conducted because the plant had regressed to the point that only 250 acres remained in the lake. The Illinois River arm is the only area that seems to have been totally unaffected by the regression.

It is planned to continue remote sensing on Kerr in an attempt to detect any reversal of the regression that might lead to a similar bloom of the Eurasian watermilfoil that was experienced in 1977. Tulsa District will continue monitoring the water quality conditions of Kerr and is planning to initiate physiological and ecological studies of the watermilfoil. It is felt that, if another bloom occurs, the information from these studies might indicate what condition or conditions cause the drastic fluctuations in plant population. That information could lead to development of new control techniques.

CHEMICAL CONTROL TECHNOLOGY DEVELOPMENT

An Overview

by

Howard E. Westerdahl*

Introduction

The Aquatic Plant Control Research Program's (APCRP) Chemical Control Technology Development Project (CCTDP) was organized into specific tasks representing vital research areas. This approach provides Corps of Engineer (CE) District Offices, Federal and State agencies, and chemical corporations with a concise summary of the rationale and proposed research for specific tasks within the CCTDP.

The objective of the CCTDP is to identify, evaluate, and provide new herbicide formulations and application techniques for the control of both emergent and submergent aquatic plants. Six interrelated task areas were identified as major components required to meet this objective:

Task I: Research Identification, Management, and Technology Transfer

Task II: Identification and Development of New Herbicide Formulations and Chemical Plant Growth Inhibitors

Task III: Screening and Evaluation of New Herbicide Formulations and Chemical Plant Growth Inhibitors

Task IV: Field Demonstrations

Task V: Herbicide Application Techniques and Equipment Design

Task VI: Legal and Economic Constraints to New Herbicide Development

These tasks carefully integrate research approaches to ensure adequate coordination and evaluation of results prior to field testing new herbicide formulations or initiating production of a promising new formulation. Each task area is comprised of several interrelated work units, each addressing specific research objectives. Work units can be added and deleted based on research accomplishment and identification of new or continuing research needs.

* U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

Task I: Research Identification, Management, and Technology Transfer

Rationale

Past aquatic herbicide research and testing has been undertaken with limited coordination between developer and user. Many potentially useful products and techniques have not been effectively evaluated because of inadequate technology transfer. Technology evaluation and transfer is especially lacking for small companies and universities in development and testing of herbicides. Moreover, many companies are discouraged from developing new herbicide products because of insufficient or inaccurate guidance concerning present and proposed Government regulations and evaluation requirements.

Objective

The objectives of Task I are: to identify pertinent research needs; to coordinate with industry and other Federal and State agencies on current research progress and testing thus minimizing duplication of research; to provide technology evaluation and transfer of relevant information concerning new herbicide formulations and application techniques to CE Districts; and to coordinate task area investigations.

Approach

Personal, telephone, and written communications will be made routinely with pertinent CE Districts to identify research needs and to develop mutual cooperation in field demonstrations of new herbicide formulations. Likewise, other Federal and State agencies responsible for aquatic plant research and control will be notified for coordination of research needs and field evaluation. Mutual cooperation will reduce costs to each agency and provide thorough fate and effect evaluations of selected herbicide formulations. Those chemical companies which have submitted, during FY 80, herbicide formulations to the USDA Aquatic Plant Management Laboratory for evaluation will be notified to assess the potential for cooperative research efforts, possibly leading to registration of the formulation.

The results of in-house and contracted research from other tasks will be presented through scheduled workshops, input to the APCRP Information Exchange Bulletin, symposia and professional society input, Engineer Technical Letters, and production of an Aquatic Herbicide Handbook during FY 82. The Aquatic Herbicide Handbook will include specific information on the chemical and toxicological characteristics of each herbicide and guidance on application techniques and equipment necessary for environmentally safe treatment of nuisance aquatic plants.

Task II: Identification and Development of New Herbicide Formulations and Chemical Plant Growth Inhibitors

Rationale

The development, registration, and marketing of new aquatic herbicide formulations have been hindered by increased testing requirements for new product registration, escalating costs for research and development, and significant regulatory constraints at the Federal and State levels. Furthermore, the technology and basic research presently exist for developing new, environmentally compatible herbicide formulations; however, the uncertainty associated with projections of long-term profits and product demand often hinders new product development.

Objective

The objective of this task is to identify and evaluate new herbicide formulations for their potential as effective aquatic plant control agents. Research emphasis is on developing new formulations of registered herbicides and naturally occurring chemical plant growth inhibitors.

Approach

Research and development of new aquatic herbicide formulations will be initiated by: identifying research and development activities by industry, Government agencies, and universities; funding basic research in promising areas; and funding preliminary laboratory testing of new formulations. Major research emphasis will be: (a) the development of controlled-release herbicide formulations; (b) the isolation and development of naturally occurring plant growth regulators/inhibitors; and (c) the evaluation of integrated aquatic plant management methods which cônsider herbicide treatment in combination with biological or mechanical control methods. Controlled-release herbicide formulations being evaluated include encapsulation of herbicides in solid granular or fibrous polymeric matrices, microencapsulation in simple or complex emulsions, and bonding of herbicides onto assorted active surfaces. The modes of herbicide release from the various matrices include rate-controlled diffusion, hydrolysis of ester links, chemical breaking of ionic or covalent bonds, desorption by ion exchange mechanisms, biodegradation, rate-controlled matrix erosion, and solubility-controlled removal of a solid matrix material. The herbicides are in either solid or liquid form with single or multiple-layered matrices. Other areas of interest include: isolation, identification, and synthesis of naturally occurring plant growth regulators; and integrated management of aquatic plants, using combinations of chemical, biological, and mechanical control methods.

Task III: Screening and Evaluation of New Herbicide Formulations and Chemical Plant Growth Inhibitors

Rationale

Recent amendments (October 1978) to the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) of 1976 no longer require registration submission of herbicide efficacy data on target and nontarget plants. These data are required for establishing ecological effects. The U. S. Environmental Protection Agency (EPA) may request this information during the review of a petition for herbicide registration. The Toxic Substances Control Act (TSCA) requires chemical companies to submit a premanufacture notification to EPA whenever a previously inventoried toxic substance is employed in a manner significantly different from the existing use. This notification applies to new herbicide formulations and registered herbicides whenever an approved use is expanded. The FIFRA and TSCA are ambiguous concerning specific data requirements. Consequently, a chemical company may not commit a new product development or expansion of a herbicide's use without completing extensive efficacy screening on target and nontarget plants and conducting limited laboratory or field evaluations to assess the product's environmental fate and effects.

Only a few of the major chemical companies have ongoing efficacy screening programs. The smaller companies may have contractors perform this function. Consequently, no uniform procedure has been developed for screening herbicides. The results from different groups involved in aquatic herbicide screening may vary considerably. In general, present screening programs rely on long-term (approximately 2 to 3 months) monitoring of gross physiological changes in target and nontarget aquatic plants. The initial screening is usually conducted in small containers under artificial lighting or in small containers located in greenhouses. The long-term monitoring limits the number of test replications and products that can be evaluated annually.

Guidance for aquatic toxicology and environmental fate and effects testing of new herbicide formulations is similarly ambiguous under FIFRA. As a result, chemical companies invest millions of dollars and several years in laboratory and field testing to obtain requisite data only to discover still other tests to be run following review of the data by regulatory agencies. As listed in the FIFRA, multiple organisms and procedures for a specific test are referenced for selection by chemical companies. Many times the chemical companies discover that the regulatory agencies will request the test repeated with different organisms or procedures. Consequently, the lack of specific guidance may preclude economic considerations as the main obstruction to companies involved in new product development.

Objective

The objectives of this task are: to evaluate efficacy data on target aquatic plants resulting from new herbicide treatments; to

determine herbicide effects on select nontarget organisms; to determine effective threshold concentrations of the existing and new herbicide formulations; to evaluate chronic toxicities of selected controlled-release herbicide formulations; to obtain, when feasible, requisite test data for Federal and State registration of the most promising aquatic herbicides; and to recommend the most promising new herbicide formulations for field testing or further laboratory evaluation.

Approach

A concerted effort will be made through interagency meetings and workshops with leading authorities and researchers to recommend an improved, standardized, aquatic herbicide screening program. Major emphasis of the screening program will be toward interlaboratory (i.e., Federal, State, and private) standardization of methods. Development of short-term, cost-effective evaluation procedures for conventional and controlled-release herbicide formulations and herbicide/adjuvant combinations will be an important objective of the improved screening program. Currently, the most promising approach for evaluating short-term herbicide efficacy is to develop direct micro-scale detection procedures, e.g., assessing damage to apical tissues and cellular organelles. Indirect methods may include monitoring of plant respiration rate, carbon fixation, and/or chlorophyll assays.

The development of controlled-release herbicide formulations which are capable of delivering low levels of herbicides over several months into the aquatic environment has presented new testing requirements: (a) the threshold herbicide concentration required to kill apical meristems, root crowns, and other reproductive structures must be determined prior to field testing; and (b) the chronic toxicity of various herbicides to select nontarget organisms, which is associated with prolonged, low-level herbicide exposure, must be evaluated.

When advantageous to both the herbicide developer and the APCRP, mutual cooperation may be feasible for conducting toxicological and general environmental fate and effects testing as required under the FIFRA for herbicide registration.

Task IV: Field Demonstrations

Rationale

Specific guidance for test site selection and experimental design of field demonstrations for evaluating herbicides is not generally available. Consequently, field test plans and site conditions have varied significantly. Furthermore, there has been slow development of aquatic plant control management strategies which consider multiple herbicide applications, frequency of application, and alternate application techniques for optimizing plant control and minimizing costs. Clear, concise guidance is needed concerning test site selection and development of technically sound research plans. Permits from Federal and State

regulatory agencies are rapidly processed if test results from well-designed research describe the environmental fate and effects of new herbicide formulations.

Objective

Through cooperation with private industry, the appropriate test plans and requisite field data will be developed to describe the environmental fate and effects of new herbicide formulations. Also, the feasibility for optimizing aquatic plant control through multiple herbicide combinations, frequency of application, and alternate application techniques will be assessed.

Approach

Mutual cooperation among the U. S. Army Engineer Waterways Experiment Station, CE, Districts/Divisions, chemical companies, and other Government agencies will be continued to ensure that field demonstrations satisfy most of the requirements for Federal and State registration. Cooperative efforts will include preparation of documentation for field test plans and evaluation of test results. The CE Districts/Divisions may be requested to assist in locating field sites, providing field assistance, and coordinating activities with concerned local citizenry. The field demonstrations will be developed to provide information on application rates, rate of herbicide dispersion, nontarget plant interactions, plant degradation rates, and water quality impacts.

Recommendations from Task V concerning application techniques and multiple herbicide treatments for optimizing aquatic plant control will be evaluated. The best combination of herbicides and application techniques will be field tested following recommendations by licensed aquatic herbicide applicators in various states and chemical companies. Specific recommendations will be provided in the Aquatic Herbicide Handbook, technical reports, and through the APCRP Information Exchange Bulletin.

Task V: Herbicide Application Techniques and Equipment Design

Rationale

Equipment designs and application techniques used for agricultural and horticultural crops also have been used to apply herbicide formulations to floating, emergent, and submergent aquatic plants. Liquid herbicides may be dispersed by airplane or helicopter, hand spraying from a boat, or injected into the water through weighted trailing hoses. Likewise, granular formulations may be dispersed by plane or helicopter, cyclone-type spreaders from a boat, or motorized blower units from a boat. Wind drift is a severe problem for liquid herbicide application. Hand dispersal of liquid and granular herbicides requires a constant boat speed through weed-infested areas and

rigid control of the herbicide amount being dispersed to ensure the appropriate rate of application and areal coverage.

A lack of adequate design criteria and performance standards for aquatic herbicide application equipment that may be applied industry-wide has resulted in a serious lack of uniformity in equipment designs and application techniques. Most of the granular application equipment is built by the individual licensed applicators. Consequently, many variations of similar equipment are in use. The quality control associated with uniform herbicide dispersal over a given area at different ~~rates of~~ application is a function of how conscientious the applicator is in equipment calibration, quality of equipment design, and control of boat speed through infested areas. Consequently, the variability in herbicide efficacy may be due to the ~~variability in~~ application equipment and techniques used by individual applicators and less attributable to the herbicide and characteristic environment in which the herbicide was applied.

Objective

The objectives of this task are to evaluate existing equipment and application techniques for improving equipment design, herbicide efficacy, and manpower efficiency; and to reduce the potential for adverse health effects to applicators.

Approach

An extensive review and evaluation (see Task IV) will be conducted of equipment specifications and application techniques which are currently in use for applying aquatic herbicides. Specific recommendations and guidance will be provided in the Aquatic Herbicide Handbook. As new equipment, application techniques, and chemical adjuvents are developed and identified, these will be added to the Aquatic Herbicide Handbook and to research summaries for the APCRP Information Exchange Bulletin. Information from licensed herbicide applicators from selected states will be obtained via telephone and letter questionnaires. They will be requested to provide descriptions of application techniques for diverse aquatic environments and relative costs for the type of applications.

Task VI: Legal Economic Constraints to New Herbicide Development

Rationale

Corporate decisions concerning new herbicide development, registration, and marketing are primarily influenced by existing legal and economic constraints. The often ambiguous and rapidly changing environmental regulatory criteria and registration procedures make herbicide development and marketing a very laborious, time-consuming, and expensive endeavor. For example, as of October 1978, the FIFRA was

amended to provide for generic registration of each active ingredient in a herbicide formulation. Following selection of appropriate testing requirements, all herbicide formulations must be resubmitted to the EPA for re-registration. Also, the indefinite and complicated interrelationships of many Government regulations are unclear to those manufacturers and potential users with active research and herbicide development programs. This creates high investment risks and tends to prohibit development of new herbicide formulations.

Objective

The primary objectives of this task are: to identify and disseminate new and improved guidance from Federal and State agencies concerning testing, registration, and field application of new herbicide formulations; and to evaluate economic constraints influencing herbicide research and development.

Approach

Through routine communication via telephone, meetings, and/or workshops with State and Federal regulatory agency personnel, the development of simplified flow diagrams, tables, etc., will be provided for clarifying regulations cited in the FIFRA and/or subsequent legislation. In conjunction with model substance profiles, being generated by the Toxic Substances Control Act Interagency Testing Committee, these summaries will provide an incentive to chemical companies by clarifying requirements. These summaries will not guarantee correctness, but rather will serve as guides. Specific areas to be included in these summaries are Federal and State guidelines for registering herbicides for aquatic use.

CHEMICAL CONTROL TECHNOLOGY DEVELOPMENT

Development of Controlled-Release Herbicide Technology Using Polymers

by

Frank W. Harris* and Chike O. Arah*

Introduction

Controlled-release herbicides that may afford extended control of aquatic weeds have been developed.[1-9] One route to such formulations has been the synthesis of hydrophilic copolymers containing herbicides as pendent substituents. The herbicides are slowly released from these systems by the hydrolysis of the herbicide-polymer bonds; however, the rates of release do increase as the hydrolysis proceeds. The autoaccelerations in rates are accompanied by the gradual dissolution of the copolymers. Recently, a cross-linked copolymer has been prepared that slowly releases its herbicide at a nearly constant rate.[3] The material swells slightly but does not dissolve as the hydrolysis proceeds.

The major goals of the study were to further investigate the effect of cross-linking on the rates of hydrolysis of copolymers of this type and to investigate the copolymerization of a previously prepared herbicidal monomer with a new hydrophilic comonomer, i.e., glyceryl methacrylate (GMA). The specific objectives of this work were: (a) to copolymerize 2-acryloyloxyethyl 2,4-dichlorophenoxyacetate (AOE 2,4-D) with 2-hydroxyethyl methacrylate (HEMA) in the presence of varying amounts of the trifunctional cross-linking agent, pentaerythritol triacrylate (PETA), and the difunctional cross-linking agent, 2,2-dimethylpropanediol dimethacrylate (DPDM); (b) to copolymerize 2-methacryloyloxyethyl 2,4-dichlorophenoxyacetate (MOE 2,4-D) with varying amounts of GMA; and (c) to determine the hydrolysis rates of all the polymers perpared under slightly alkaline conditions (pH = 8.00) at ambient temperature.

Results and Discussion

Monomers

AOE 2,4-D and MOE 2,4-D were prepared by the reaction of 2,4-dichlorophenoxyacetyl chloride with HEA (2-hydroxyethyl acrylate) and

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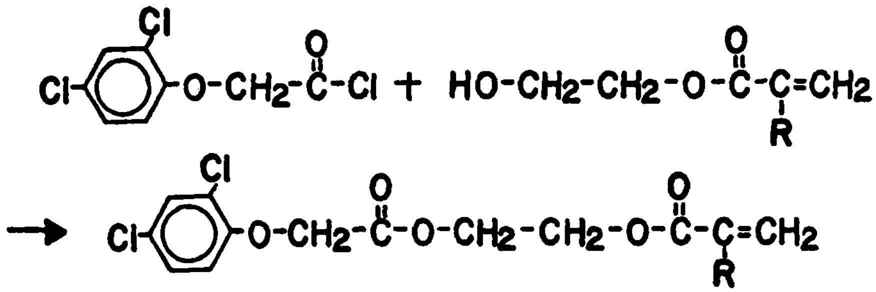
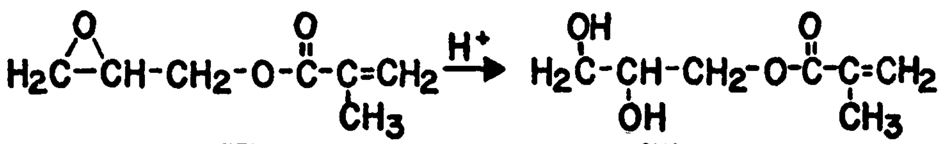
HEMA, respectively.[1] Both reactions were carried out in the presence of N, N-dimethylaniline (DMA), which was used to neutralize the liberated hydrochloric acid. The reaction is as follows:



1 R = H AOE 2,4-D

2 R = CH_3 MOE 2,4-D

GMA was prepared by acid hydrolysis of EPMA:[10]



EPMA GMA

<u>Cross-linked AOE 2,4-D/HEMA copolymers</u>

A series of copolymerizations of AOE 2,4-D and HEMA was carried out with equimolar amounts of the two monomers in the presence of 2, 4, and 8 percent (w/w) PETA and 2, 4, and 8 percent (w/w) DPDM (Tables 1 and 2). The polymerizations, which were conducted in varying amounts of MEK (methyl ethyl ketone) at 70°C, were run until gelation occurred. The white polymers were isolated by precipitation in hexane and then extracted overnight with ether in order to remove any unreacted monomers and initiator residues. The yields of the polymers ranged from 26 to 91 percent.

The cross-linked products (Figures 1 and 2) are insoluble in organic solvents. The Tg's (glass transition temperatures) of the networks range from 45° to 50°C, with the Tg's of the trifunctionally cross-linked polymers being higher than their difunctionally cross-linked counterparts (Tables 1 and 2).

<u>Linear MOE 2,4-D copolymers</u>

MOE 2,4-D was then copolymerized with HEMA and GMA. The MOE 2,4-D/comonomer molar feed ratios used were 70:30, 60:40, and 50:50. The copolymerizations were conducted in MEK at 70°C with AIBN* (0.016 g)

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* AIBN = azobisbutyronitrite.

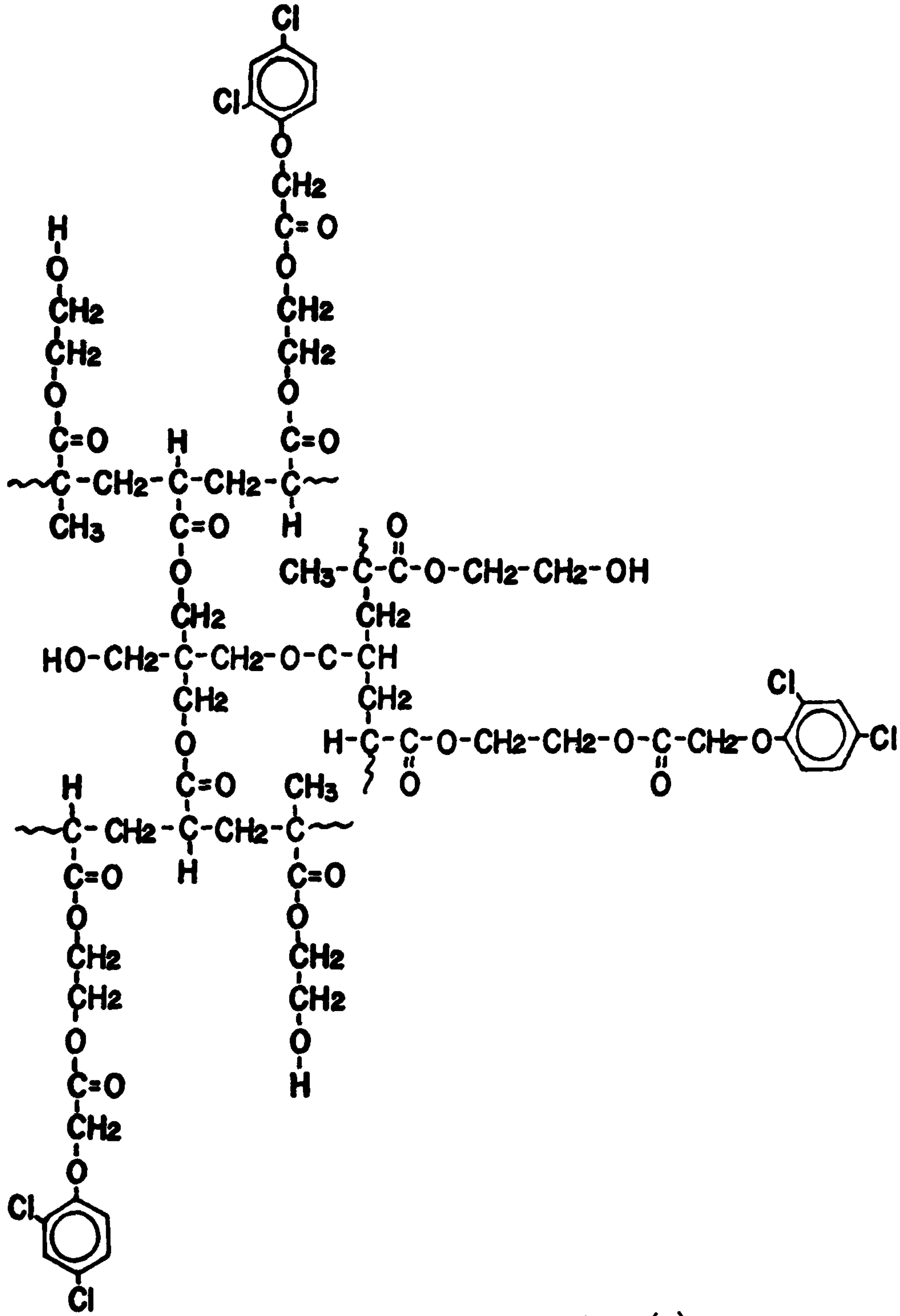


Figure 1. AOE 2,4-D/HEMA/PETA (3)

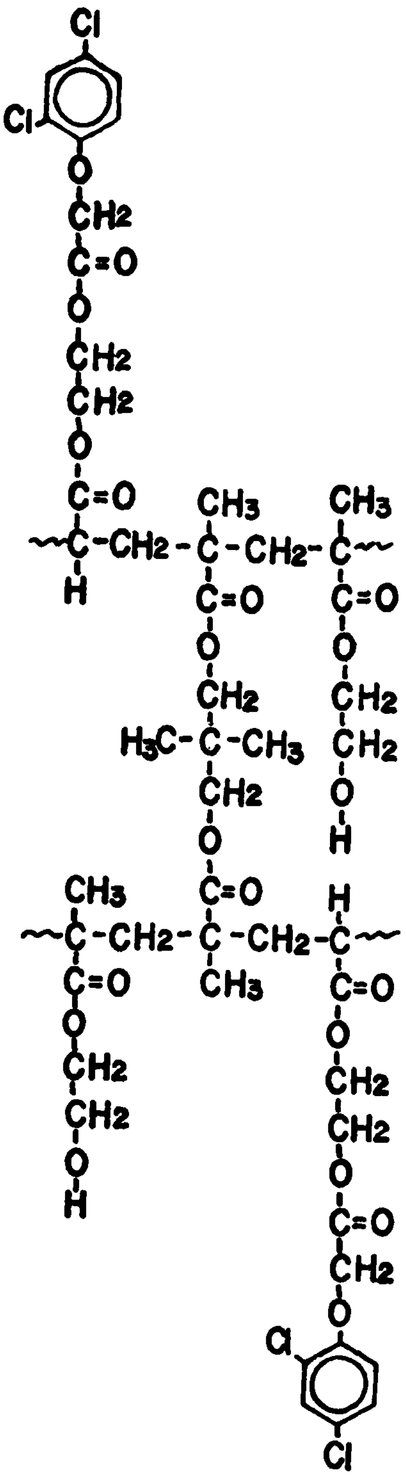
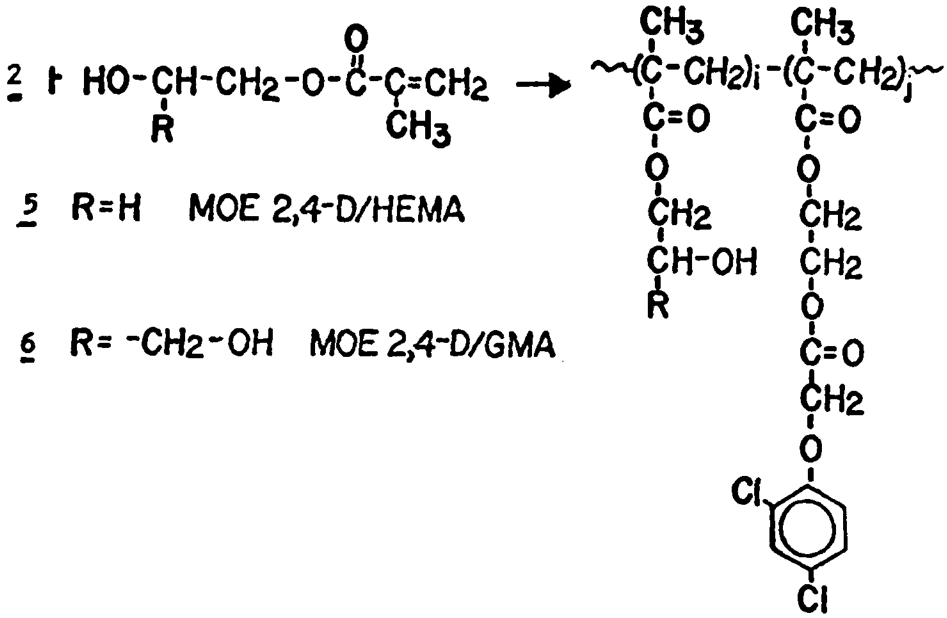


Figure 2. AOE 2,4-D/HEMA/DPDM (4)

as the initiator. The products were isolated by precipitation in hexane and then extracted overnight with ether. The yields of the copolymers ranged from 50 to 95 percent (Table 3).



An attempt was also made to copolymerize MOE 2,4-D with crotonic acid. In this case, however, only MOE 2,4-D homopolymer could be isolated from the reaction mixture.

Copolymers 5 and 6 are soluble in several organic solvents, such as THF (tetrahydrofuran), DMF (dimethylformamide), and aliphatic ketones, but are insoluble in aliphatic hydrocarbons, ethyl ether, and water. The Tg's of these polymers range from 50 to 68°C (Table 3).

Hydrolysis studies

Three 0.5-g samples of each copolymer were immersed in a buffer solution (pH = 8.00) of boric acid and sodium hydroxide and stored at ambient temperature. The amount of 2,4-D released from each replicate was periodically determined by spectrophotometric analysis.

The MOE 2,4-D/HEMA copolymers did not undergo hydrolysis under these conditions. The hydrolysis data for the other linear and cross-linked copolymers are summarized in Tables 4-8 and Figures 3-6.

The hydrolysis data suggest that the release rates of the cross-linked copolymers are strongly dependent upon hydrophilicity. As with the previously studied linear copolymers, the rates increase with increases in the degree of hydrophilicity.[3] Although there is some evidence that an increase in the degree of cross-linking may result in a slight decrease in the rate of hydrolysis, the hydrophilicity, as

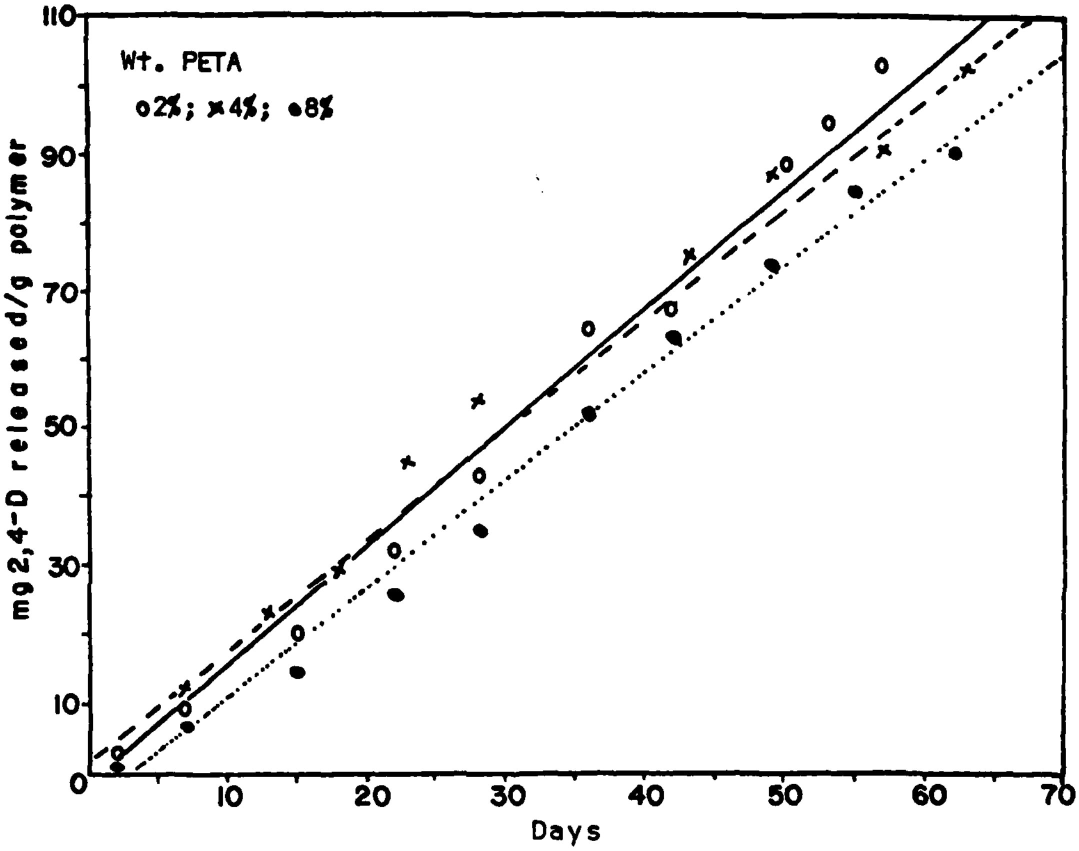


Figure 3. Hydrolysis of polymer 3 prepared in 25 ml MEK

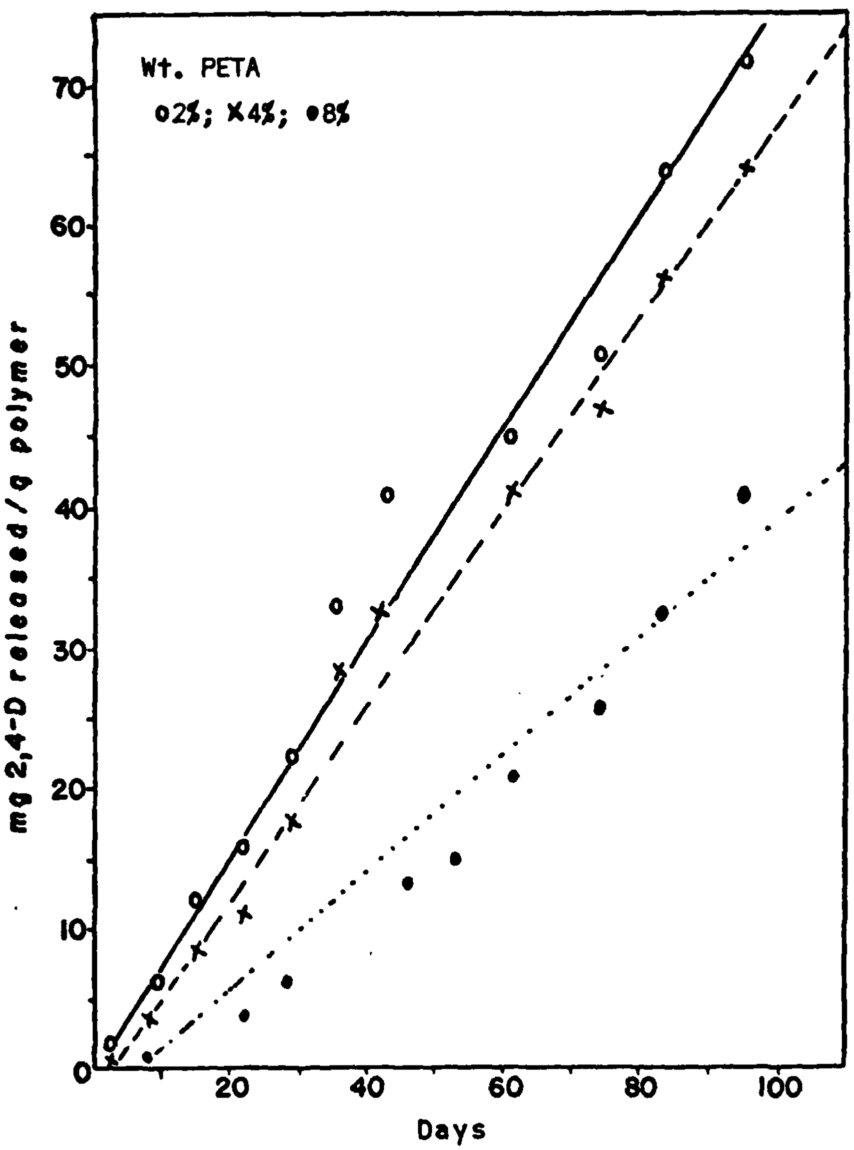


Figure 4. Hydrolysis of polymer 3 prepared in 80 ml MEK

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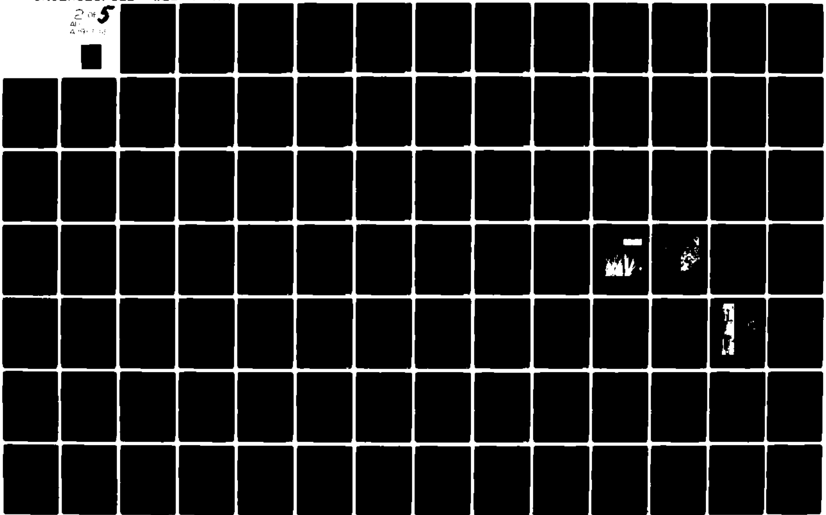

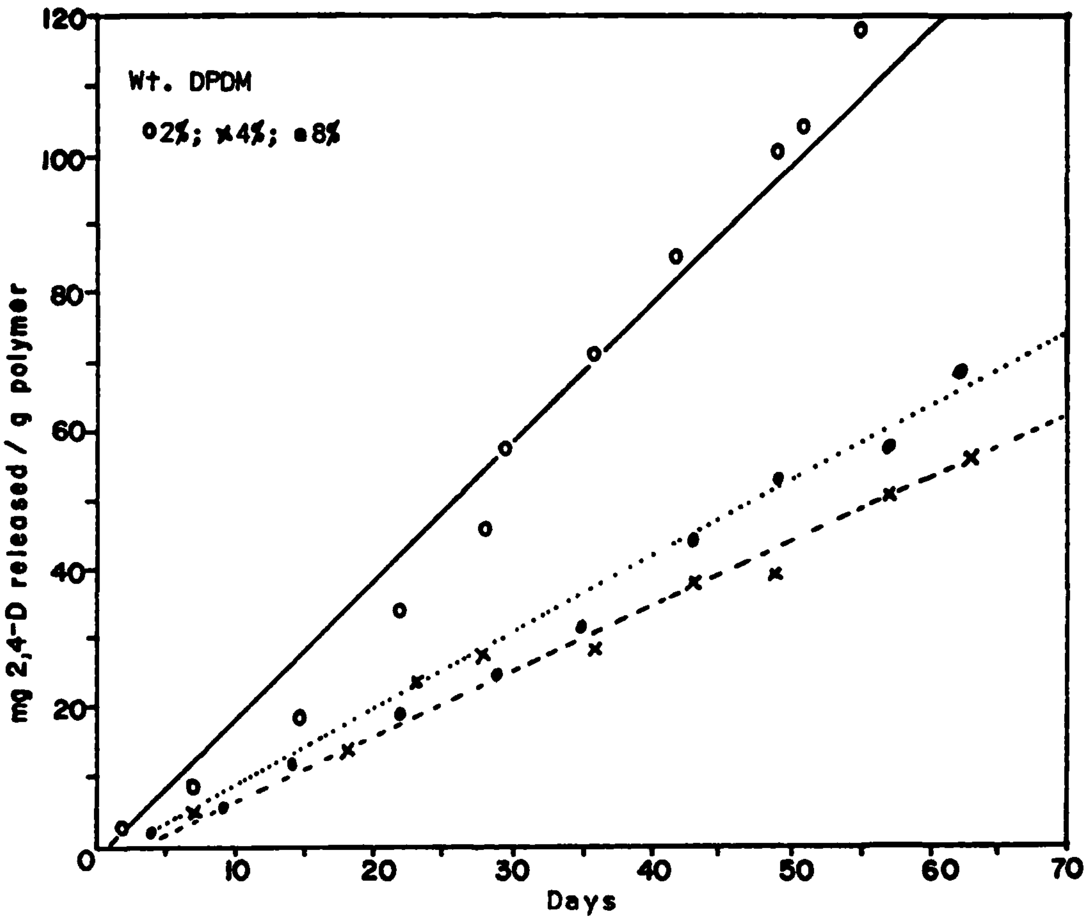

Figure 5. Hydrolysis of polymer 4 prepared in 25 ml MEK

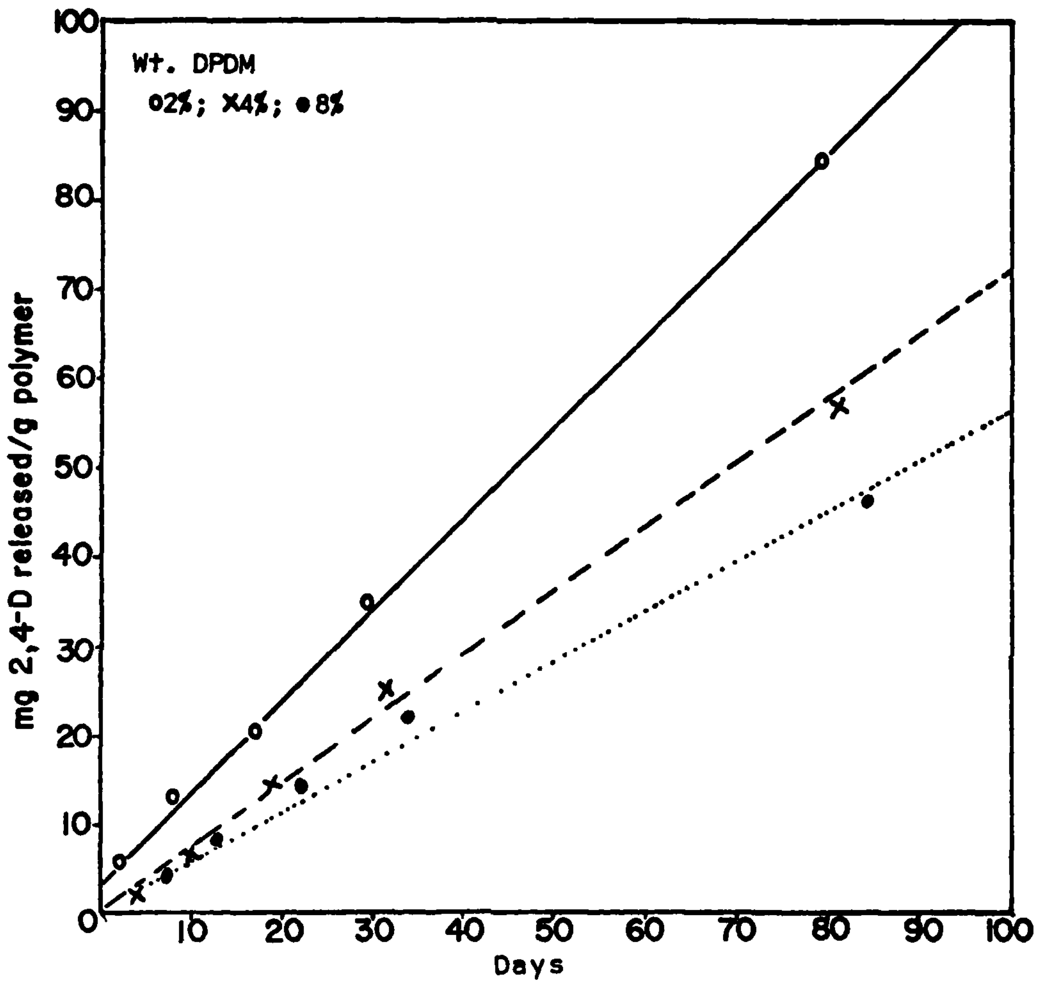

Figure 6. Hydrolysis of polymer 4 prepared in 50 ml MEK

determined by the copolymer's composition at the time of gelation, appears to be the major factor governing the rate at which a given copolymer undergoes hydrolysis. For example, copolymer 3a hydrolyzes more than twice as fast as 3b although it has a considerably higher degree of cross-linking (Table 1). This can be attributed to its higher HEMA content, i.e., its higher HEMA/AOE 2,4-D ratio. Another contributing factor may be the hydrophilicity of the cross-linking agent itself. Since PETA contains a free hydroxyl group, the incorporation of this molecule into the network may result in an increase in hydrophilicity.

An additional example of the overriding effect of composition can be found by comparing polymers 3a, 3c, and 3e. These copolymers undergo hydrolysis at similar rates despite their large differences in degree of cross-linking. Their hydrophilicities, as determined by their HEMA and PETA contents, however, are very similar.

There is some indication that the degree of cross-linking may be more important in less hydrophilic copolymers, i.e., copolymers containing lower HEMA/AOE 2,4-D ratios. For example, polymers 3b, 3d, and 3f have similar composition but slightly different release rates. In fact, the release rates do decrease as the degree of cross-linking increases (Table 1).

Interesting examples of the effects of composition and cross-linking can also be found by examining the results of the cross-linking studies with DPDM (Table 2). Since DPDM contains two methyl groups, the incorporation of this molecule in a network should result in a decrease in hydrophilicity. This may partially explain why 4g releases 2,4-D at one half the rate of 4a. Of course, the reduced rate may be due to 4g's significantly higher cross-link density. Considering the results of the PETA studies, however, it is more likely that the large difference in rates is due to the difference in composition.

All of the cross-linked systems release 2,4-D at nearly constant rates. This is in contrast to linear AOE 2,4-D/HEMA copolymers which undergo autoaccelerating hydrolysis. The explanation for this difference in behavior is not apparent.

In contrast to all the previously prepared MOE 2,4-D copolymers and the MOE 2,4-D/HEMA copolymers, the MOE 2,4-D/GMA copolymers underwent hydrolysis under the mild alkaline conditions. Evidently, the extra hydroxyl group in GMA imparted enough hydrolysis to the copolymers to permit hydrolysis to proceed. The rate of hydrolysis did increase as the amount of GMA in the copolymer increased (Table 8 and Figure 7). Surprisingly, the rates remained relatively linear throughout the study. This is similar to the behavior of the cross-linked systems and may be related to the fact that the copolymers did not go into solution as the hydrolyses proceeded. (The autoaccelerations in the hydrolyses of AOE 2,4-D/HEMA copolymers are accompanied by the polymers' gradual dissolution.)

The nearly constant release rates of the MOE 2,4-D/GMA copolymers

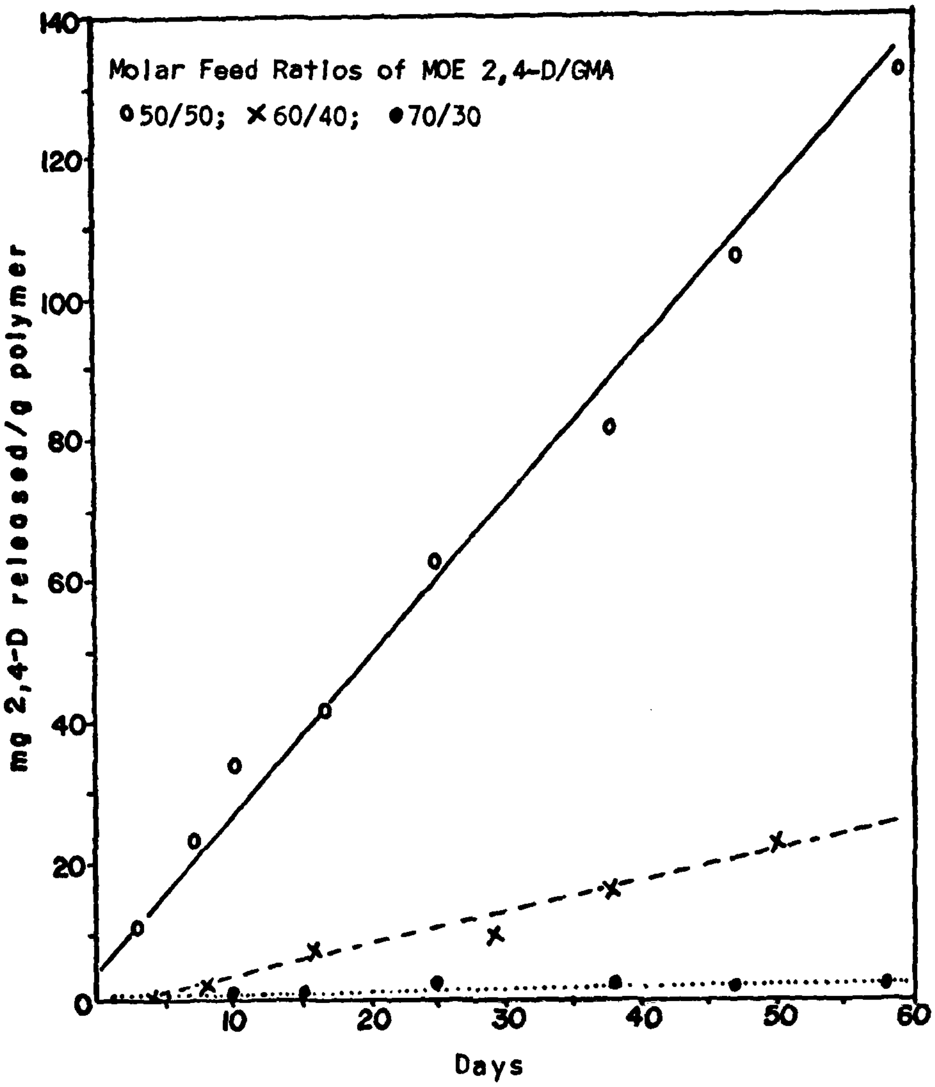

Figure 7. Hydrolysis of MOE 2,4-D/GMA copolymers

and their relatively high Tg's make them excellent candidates for use in aquatic weed control. These systems will be studied extensively in this laboratory in the near future.

Experimental

Reagents

The HEA, HEMA, 2,3-epoxypropyl methacrylate (EPMA), and DPDM were purchased from Polysciences, Inc. The DPDM and HEMA used in

polymerization were distilled under reduced pressure immediately before use. The PETA was obtained from Celanese Chemical Company and was used without further purification. The 2,4-D was purchased from Aldrich Chemical Company and Eastman Kodak Company and used without further purification. The AIBN was purchased from Matheson Coleman and Bell Company and was recrystallized from methanol. The MEK was purchased from Fisher Scientific Company. Crotonic acid was purchased from Aldrich Chemical Company and sublimed before use.

Instrumentation

Infrared (IR) spectra were recorded with Perkin-Elmer 735B and 457 Grating spectrophotometers. Ultraviolet (UV) spectra were obtained with a Cary model 14 recording spectrophotometer. Inherent viscosities were determined with a Cannon number 75 viscometer in a constant temperature bath maintained at 30°C. Differential scanning calorimeter (DSC) thermograms were obtained with a Dupont 900 thermal analyzer equipped with a differential scanning calorimeter cell. Elemental analyses were performed by Galbraith Laboratories, Inc., Knoxville, Tennessee.

Monomer preparation

The AOE 2,4-D and MOE 2,4-D were prepared according to the known procedure.[1] The GMA was prepared by acid hydrolysis of EPMA according to the known procedure.[10]

General copolymerization procedure

Copolymerizations were conducted in an Ace glassware polymerization vessel equipped with a hollow trubore stirrer that permitted nitrogen to be introduced below the surface of the reaction mixture. The copolymerizations were carried out in MEK at 70°C for the designated time period (Tables 2 and 3). The GMA copolymerizations were conducted in 80 ml of MEK for 30 hr. AIBN (0.016 g) was used as the initiator. Cross-linked systems were run until gelation occurred. The reaction mixtures were added to hexane, and the resulting suspensions agitated in a Waring blender. The polymers were collected by filtration, extracted overnight with anhydrous ethyl ether to remove unreacted monomer and initiator residues, and then dried under vacuum at 34°C.

Hydrolysis study

The copolymers were sieved to obtain a uniform particle size (125 to 420 μ). Three 0.5-g replicates of each sample were placed in individual 500-ml flasks containing 300 ml of a boric acid/sodium hydroxide buffer (pH = 8.00). The flasks were equipped with sintered glass sampling tubes that allowed the buffer solutions to be removed free of any polymer particles. The amount of 2,4-D released was determined periodically by spectrophotometric analysis at 198 nm.

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Table 1

Cross-Linking Studies with PETA

Polymer No.	Volume Solvent Used in Preparation ml	Weight Percent PETA in Feed	Reaction Time, hr	Conversion percent	Tg* °C	Percent Cl	Copolymer Composition** Molar Ratios of AOE 2,4-D	HEMA	PETA	Average mg 2,4-D Released per g of Polymer per day†
3a	25	2	3††	28	48	10.77	29	66	5	1.9
3b	80	2	23‡	91	47	14.64	45	53	2	0.8
3c	25	4	2††	27	49	11.09	33	58	9	1.6
3d	80	4	23‡	85	49	13.84	42	54	4	0.7
3e	25	8	1††	32	50	9.00	26	58	16	1.6
3f	80	8	23‡	86	49	13.24	41	53	6	0.4

* Determined from differential scanning calorimeter data.
** Calculated from chlorine analysis assuming complete incorporation of the used PETA.
† Average for a period of about 60 days.
†† Actual time of polymerization, i.e. the time at which gelation occurred.
‡ Actual time of polymerization, i.e. reaction was allowed to run overnight during which time gelation occurred.

Table 2

Cross-Linking Studies with DPDM

Polymer No.	Volume Solvent Used in Preparation ml	Weight Percent DPDM in Feed	Reaction Time, hr*	Conversion percent	Tg** °C	Percent Cl	Copolymer Composition† Molar Ratios of AOE 2,4-D	HEMA	DPDM	Average mg 2,4-D Released per g of Polymer per day††
4a	25	2	4	28	46	10.57	28	66	6	2.2
4b	50	2	44	84	45	15.35	49	49	2	1.0
4c	75	2	192	90	45	12.62	35	62	3	‡
4d	25	4	3	44	47	12.96	39	48	13	0.9
4e	50	4	7	58	47	12.02	34	60	6	0.8
4f	75	4	120	89	46	10.39	27	70	3	‡
4g	25	8	2	26	48	9.30	27	48	25	1.1
4h	50	8	19	53	47	11.92	36	52	12	0.7
4i	75	8	17	76	47	11.02	30	61	9	‡

* Actual time of polymerization, i.e. the time at which gelation occurred.
** Determined from differential scanning calorimeter data.
† Calculated from chlorine analysis assuming complete incorporation of the used DPDM.
†† Average for a period of about 60 days.
‡ No hydrolysis data were obtained.

Table 3

Physical Properties of MOE 2,4-D Copolymers

Comonomer	Mole Percent MOE 2,4-D in Feed	Conversion percent	Elemental Analysis percent C	H	Cl	Mole Percent MOE 2,4-D in Copolymer*	Average mg 2,4-D Released per g of Polymer per day**	η†	Tg†† °C	IR, cm^{-1}
HEMA	60‡	50	51.35	5.14	16.77	59	0.0	0.79	60	3430 (OH) 1720 (C=0)
HEMA	50‡	53	52.64	5.58	15.62	51	0.0	0.74	65	3400 (OH) 1710 (C=0)
GMA	70‡‡	94	51.73	5.28	17.43	68	0.1	0.16	50	3460 (OH) 1730 (C=0)
GMA	60‡‡	94	50.70	5.39	15.45	56	0.4	0.18	53	3440 (OH) 1720 (C=0)
GMA	50‡‡	95	50.75	5.68	13.49	45	2.5	0.25	68	3420 (OH) 1720 (C=0)

Note: IR = infrared.
* Determined from chlorine analysis.
** Average for a period of about 60 days.
† Inherent viscosity (0.50 g/dl in DMF at 30°C).
†† Determined from differential scanning calorimeter data.
‡ 35 ml MEK used in polymerization.
‡‡ 80 ml MEK used in polymerization.

Table 4

Hydrolysis Data for AOE 2,4-D/HEMA Copolymer Cross-Linked with PETA*

	2 Percent PETA			4 Percent PETA			8 Percent PETA	
Days	mg 2,4-D per g Polymer	Percent 2,4-D Released	Days	mg 2,4-D per g Polymer	Percent 2,4-D Released	Days	mg 2,4-D per g Polymer	Percent 2,4-D Released
2	2.8	0.8	7	12.1	3.5	2	2.0	0.7
7	9.9	3.0	13	23.7	6.9	7	7.7	2.7
15	20.4	6.1	18	29.1	8.4	15	15.9	5.7
22	32.1	9.6	23	45.3	13.1	22	26.4	9.4
28	42.9	12.8	28	54.4	15.8	28	35.0	12.5
36	65.7	19.6	43	75.4	21.8	36	52.7	18.8
42	68.1	20.3	57	90.2	26.1	42	63.1	22.5
50	89.5	26.7	63	102.9	29.8	49	49.7	28.4
53	95.9	28.7	71	113.6	32.9	55	85.7	30.5
57	103.3	30.8	88	120.3	34.8	62	90.9	32.4

* 25 ml MEK used in polymerization.

Table 5

Hydrolysis Data for AOE 2,4-D/HEMA Copolymer

Cross-Linked with PETA*

2 Percent PETA			4 Percent PETA			8 Percent PETA		
Days	mg 2,4-D per g Polymer	Percent 2,4-D Released	Days	mg 2,4-D per g Polymer	Percent 2,4-D Released	Days	mg 2,4-D per g Polymer	Percent 2,4-D Released
2	1.5	0.3	2	0.5	0.1	2	0.0	0.0
9	6.2	1.4	9	3.8	0.8	9	1.1	0.3
15	12.3	2.7	15	8.5	1.8	15	2.4	0.6
22	15.6	3.4	22	11.4	2.4	22	3.8	0.9
29	22.3	4.9	29	17.9	3.8	28	6.4	1.6
36	33.0	7.2	39	32.9	6.9	36	9.0	2.2
43	41.2	9.0	42	35.5	7.5	46	13.2	3.2
61	45.4	10.0	61	41.2	8.7	53	14.5	3.5
74	51.6	11.3	74	47.1	9.9	61	20.2	4.9
83	63.7	14.0	83	56.4	11.9	83	32.3	7.8
95	71.7	15.7	95	64.1	13.5	95	40.9	9.9

* 80 ml MEK used in polymerization.

Table 6

Hydrolysis Data for AOE 2,4-D/HEMA Copolymer

Cross-Linked with DPDM*

2 Percent DPDM			4 Percent DPDM			8 Percent DPDM		
Days	mg 2,4-D per g Polymer	Percent 2,4-D Released	Days	mg 2,4-D per g Polymer	Percent 2,4-D Released	Days	mg 2,4-D per g Polymer	Percent 2,4-D Released
2	2.7	0.8	7	5.3	1.3	4	2.4	0.8
7	9.9	3.0	13	11.7	2.9	9	6.3	2.2
15	20.0	6.1	18	14.4	3.6	14	12.0	4.2
22	34.2	10.4	23	24.0	5.9	22	19.2	6.6
28	45.5	13.8	28	27.6	6.8	29	25.1	8.7
30	56.8	17.2	43	38.5	9.0	35	31.9	11.0
36	70.6	21.4	57	51.0	12.6	43	44.7	15.4
42	84.7	25.7	63	56.8	14.1	49	53.0	18.3
51	104.0	31.6	71	64.7	16.0	57	57.1	19.2
55	118.8	36.1	76	71.6	17.7	62	69.8	24.0

* 25 ml MEK used in polymerization.

Table 7

Hydrolysis Data for AOE 2,4-D/HEMA Copolymer
Cross-Linked with DPDM*

2 Percent DPDM			4 Percent DPDM			8 Percent DPDM		
Days	mg 2,4-D per g Polymer	Percent 2,4-D Released	Days	mg 2,4-D per g Polymer	Percent 2,4-D Released	Days	mg 2,4-D per g Polymer	Percent 2,4-D Released
2	6.0	1.3	4	2.1	0.6	7	5.0	1.4
8	13.1	2.7	10	6.4	1.7	13	8.2	2.2
17	21.4	4.5	19	14.9	4.0	22	14.9	4.0
29	34.7	7.3	31	24.7	6.6	34	22.6	6.1
79	84.5	17.7	81	57.0	15.2	84	46.6	12.6

* 50 ml MEK used in polymerization.

Table 8

Hydrolysis Data for MOE 2,4-D/GMA Copolymers*

	Molar Feed Ratio MOE 2,4-D/GMA 70/30			Molar Feed Ratio MOE 2,4-D/GMA 60/40			Molar Feed Ratio MOE 2,4-D/GMA 50/50	
Days	mg 2,4-D per g Polymer	Percent 2,4-D Released	Days	mg 2,4-D per g Polymer	Percent 2,4-D Released	Days	mg 2,4-D per g Polymer	Percent 2,4-D Released
1	0.3	0.1	1	0.5	0.1	1	4.2	1.0
3	0.5	0.1	4	1.8	0.4	5	19.2	4.6
5	0.9	0.2	8	2.8	0.6	17	42.7	10.2
10	1.1	0.2	16	7.5	1.6	25	63.7	15.2
17	1.4	0.3	29	9.7	2.0	38	82.4	19.6
25	2.3	0.4	38	16.4	3.4	47	106.3	25.3
38	2.4	0.4	50	22.4	4.7	59	139.8	33.3
59	2.7	0.5	100	56.0	11.6	109	219.1	52.1

* 80 ml MEK used in polymerization.

CHEMICAL CONTROL TECHNOLOGY DEVELOPMENT

Elastomeric Controlled-Release Herbicide Formulations

by

George A. Janes* and C. A. Cogley*

Introduction

The Creative Biology Laboratory is a nonprofit corporation chartered under the laws of the State of Ohio to do scientific research. Our expertise lies in the area of controlled release. Company research has included many interesting areas including snails, marine fouling, fertilizers, sun screens, mosquitoes, and mildew. We have also derived a lot of humor from efforts on serious projects with woodpeckers, coyotes, pigs, and vampire bats.

The objective of our Corps of Engineer funded research is the investigation of the application of controlled release to the problems of aquatic plants. The following controlled-release methods have been employed in this research effort:

a. Diffusion-dissolution.

b. Exfoliation.

c. Leaching.

Polymers have been used as controlled-release (CR) carriers in almost all of this effort with particular emphasis on the elastomers, or rubberlike materials. These carriers have proven uniquely suitable for controlled-release applications. They have many physical properties that make them well suited for this function, but perhaps most important is their ability to accept large loadings of bioactive materials, good weathering properties, and adaptability to a variety of final product forms.

The objective of our current Corps-funded research is the evaluation of controlled-release formulations currently in development and to refine and modify these compounds for projected field evaluations.

Background

The initial evaluation of controlled release for use against aquatic plants involved the incorporation of an active agent (2,4-D BEE)

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in a base material and examination of how effectively it was released in an aqueous environment.

The material released to the water was examined for effectiveness. The surprising efficacy of the CR material led to the chronicity study where it was found that the time dose equation expected from experience with conventional herbiciding did not hold up for chronic dosing levels. It was shown that many problem aquatic plants could be controlled with very small amounts of toxicant if it was maintained at a low level for a sufficiently long period of time. Perhaps most significant, the study demonstrated that the time penalty was not excessive.

Controlled-release aquatic herbicide development was designed to proceed on the following path:

a. Phase I. Laboratory:

(1) Release rate.
(2) Bioassay.
(3) Feedback.
(4) Processing/geometry.

b. Phase II. Laboratory and field:

(1) Release rate.
(2) Field test.
(3) Feedback.
(4) Processing/geometry.

Problems developed in that field tests were not forthcoming and laboratory evaluations had to be developed to supply information that was expected from the field.

Very early in the program it became apparent that CR materials offered an easy means of directing the toxicant. Variations of floating and sinking compounds made it possible to direct the toxicant to the phytozone where it would have the most profound effect on the plants. Evaluation of this approach confirmed the concept.

In pool tests, CR compounds containing 1 ppm 2,4-D (BEE) were evaluated against hyacinths as sinkers, floaters, and suspenders with the following results, expressed in percent mortality:

	Weeks						
	1	2	3	4	5	6	7
Suspenders	10	30	75	95	98	98	98
Floaters	5	10	10	10	10	10	12
Sinkers	2	2	2	2	2	2	2
Controls	0	0	0	0	0	0	0

The suspender version of the 2,4-D material reached control level in 4 weeks. The same material in the floater version had little effect on the plants and the sinking version had such a negligible effect that

it is doubtful it would have been noticed in a field test. It was assumed that the reason for the increased efficiency of the suspenders was that the toxicant was released at the root area and was fully absorbed by the plants.

Release rate has always been the key factor in controlled release. However, the phytozone treatment studies indicated that there is a broader concept, i.e., delivery rate, that should be emphasized. Delivery rate encompases release rate along with other factors that effect the toxicant dose brought into contact with the target plant.

Delivery Rates

Several laboratory tests have been developed to evaluate the concept of delivery rate: toxicant migration, toxicant absorption, and controlled-release position.

Toxicant migration studies give an indication of how the active agent will move in the water column. The CR material is placed at a selected point in a 6-in.-diam, water-filled tube, which is 8 ft in length. The test columns have self-sealing rubber taps at 6-in. intervals along the length. At selected intervals of time, aliquots are taken to determine the migration of the toxicant.

Toxicant absorption is evaluated by comparing the concentration variances of standard solutions subjected to different challenges. To 3-1/2-ℓ test aquaria we added:

a. *Nothing (toxic control).*

b. Plants, three strands of hydrilla.

c. Soil, 100 g in plastic cup.

d. Soil and plants.

The significance of this test can be seen in the results of an evaluation of copper sulfate.

The toxicant control retained 70 percent of original concentration after 10 weeks. The plants only absorbed 80 percent in 1 week, died, and rotted, but the toxicant was not released back into the water. The soil and plants absorbed 50 percent in 1 week and 90 percent by 9 weeks, at which point regrowth started on the plants that appeared dead.

Controlled-release position in the test aquaria alters the delivery of toxicant to the target plants.

Copper versus Hydrilla, 56 lb/acre

Pellets on bottom glass	Lethal dose (LD) 70 at 4 months, recovered to LD 60
Surface	LD 80 at 2 months, LD 100 at 4 months
On soil in cup	LD 20 at 1 month, but recovered
Controls	0% mortality

Toxicant Level in Water, 56 lb/acre

Control	2.22 ppm
Plants	0.05 ppm
Soil (CR suspended)	0.25 ppm
Soil (CR on surface)	0.15 ppm

Note: Dosing rate for CR material with 50 percent copper loading.

When half the samples were removed from the plants or soil, the release rates were comparable to that of the controls.

Microenvironments

Two groups of microenvironments were established to study the fate of the elastomer carriers in the environment. The first group, consisting of 24 units, was established in October 1977 using pond soil. The formulations used were:

Elastomer	Herbicide
SBR 4616	2,4-D acid
CB 220	2,4-D acid
SBR 1001	2,4-D acid
SN 600	Fenac
EPCAR 5465	Copper sulfate
Natural	2,4-D BEE

Each formulation was tested in duplicate along with a standard control and an elastomer blank control.

The second group, established in November 1979, consisted of 22

units. Thé three natural lake soils selected and furnished by WES were Lake Theriot, Ross Barnett Reservoir, and Eagle Lake.

The following formulations are being evaluated in duplicate against each of the three lake soils:

Elastomer	Herbicide
NRX	2,4-D acid
SBR	2,4-D acid
EPCAR 5465	Copper sulfate

There is one control for each test material.

Downstream Transmission

A flowing system provides for a quantitative comparison of the downstream transmission characteristics of conventional and CR aquatic herbicides. The flow can be modified by a variety of organic and inorganic challenges, many of which will be extensions of the delivery rate studies (Figure 1). The comparative results between different herbicide formulations will provide data for designing field tests.

The test protocol is to place selected CR herbicides in the controlled flow at the head of the system. A selected volume of water is run through the system consisting of three to six units, depending on the characteristics of the herbicide. Different application rates are evaluated at three different flow rates. Toxicant concentrations in tanks 1 through 6 at the conclusion of the run provide quantitative data on the downstream characteristics of the formulations. The following chart is typical of an unchallenged toxicant flow through the system:

Flow gal	Four Unit Downstream Tank, percent 1	2	3	4	Percent Lost
0	100	0	0	0	0
8	39	29	13	7	12
16	18	26	23	15	18
24	10	21	19	22	28
32	0	6	15	19	60
40	0	3	7	15	75
48	0	0	0	13	87
56	0	0	0	12	88
64	0	0	0	5	95
70	0	0	0	0	100

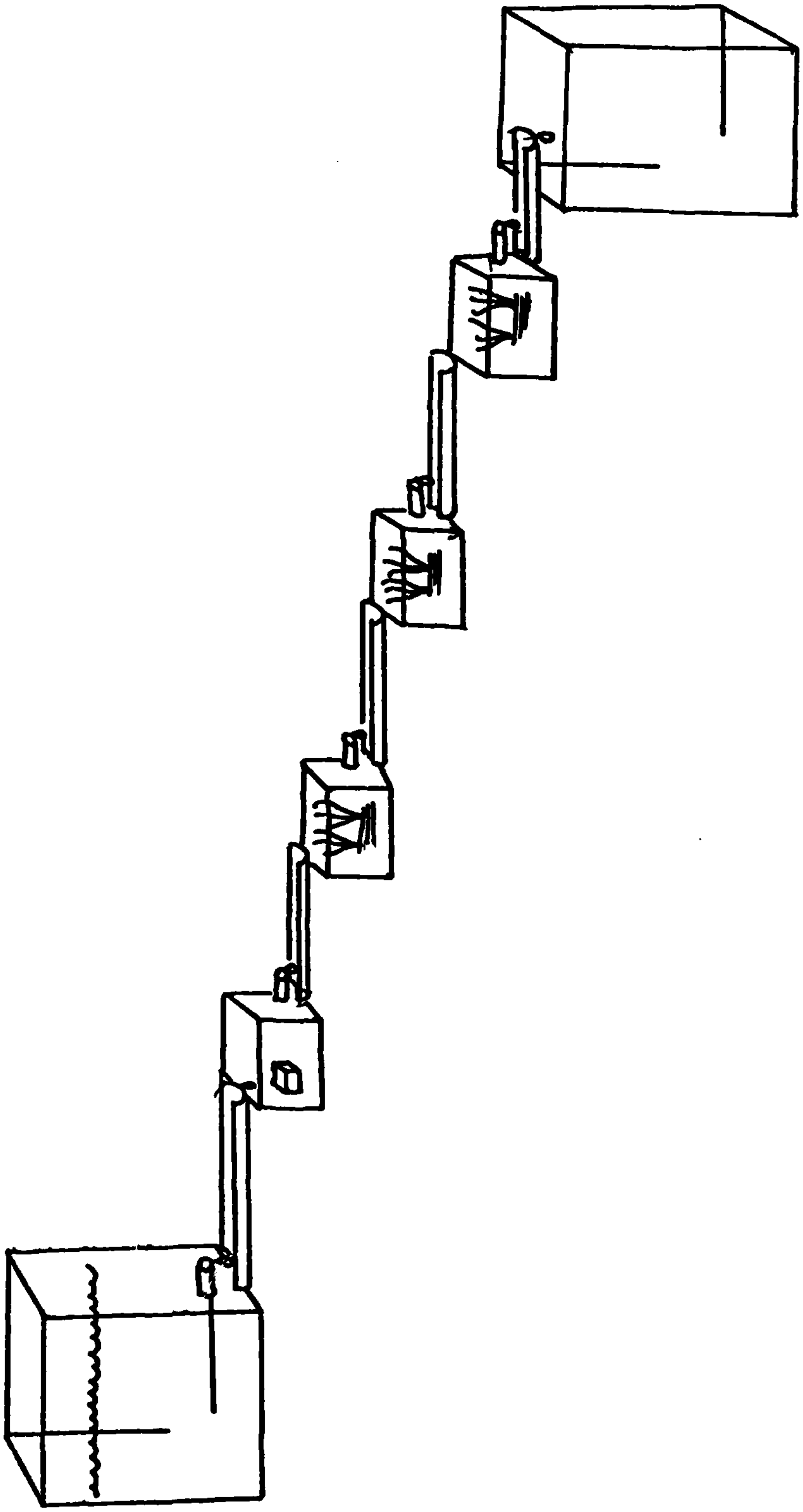

Figure 1. Downstream transmission

Each unit holds approximately 8 gal. When this volume is run through the system, the point of highest toxicant concentration moves one unit downstream. It takes eight plus volumes to move the toxicant out of a four-unit system.

CHEMICAL CONTROL TECHNOLOGY DEVELOPMENT

Screening of Chemicals for Aquatic Plant Control

by

Kerry K. Steward*

The purpose of the chemical screening project is to conduct research on the use of chemicals for aquatic weed management in an attempt to develop/discover new herbicides, growth regulators, or techniques.

Progress

This past year a variety of compounds were evaluated in the laboratory: fourteen controlled-release formulations, two coded-confidential compounds, one organic copper complex, and one adjuvant. Two chemicals were field evaluated under Experimental Use Permits (EPA). Assistance was provided in the efficacy testing of two endothall formulations against hydrilla in the Panama Canal.

Investigation of relationships between herbicide efficacy and plant nutrition indicated that plants cultured in soils to which composted manure had been added were more resistant to diquat than were plants cultured with additions of liquid fertilizer.

Controlled-release formulations of diquat have been effective, at rates as low as 0.25 mg/ℓ, against hydrilla, southern naiad, and watermilfoil.

A coded compound from Kalo Laboratories, Inc., was very effective against watermilfoil at 0.5 mg/ℓ.

Several controlled-release formulations of diquat, 2,4-D, and endothall produced complete control of watermilfoil at rates from 0.25 to 4.0 mg/ℓ.

Ten experimental and standard formulations of fenac were found to be effective against watermilfoil at a treatment rate of 0.25 mg/ℓ.

Waterhyacinth was controlled in the greenhouse with R-24191 and controlled-release formulations of 2,4-D and diquat.

Of the six fenac formulations previously run on waterhyacinth (at rates of 1.0 kg/ha and higher), retesting showed fenac plus (A 09563) to be effective at a rate of 0.1 kg/ha and fenac liquid (A 70316) and

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fenac plus dicamba (AL 3591) to be effective at a rate of 0.5 kg/ha.

Norflurazon was effective against waterlettuce at a rate of 4.0 kg/ha.

Evaluations in outside aquaria showed the coded Kalo compound and metribuzin to have been effective against waterhyacinth.

The field trial of fenac in a Broward County, Florida, lake produced 100 percent control of hydrilla after 11 months. This level of control has been maintained through 18 months.

Field testing of hexazinone and the combination of fenac plus copper TEA in small ponds near Tampa, Florida, produced complete control after 5 and 4 months, respectively. Dissolved oxygen depleted by the treatments began to return after 3 weeks.

Plans for FY 80

Conventional evaluations will be conducted on new chemicals and on new uses of registered chemicals as they are received from industry and other sources.

This year emphasis will be placed on evaluations of controlled-release herbicide formulations for control of regrowth of submersed aquatic weeds. Methods will be developed which will enable experimental formulations to be evaluated for constancy and reliability of herbicide release.

Systems utilizing flowing water synchronized with the release of herbicides from formulations will be used to evaluate the effects of constant herbicide concentrations on growth of various aquatic weed species.

The results of these evaluations are expected to provide the feedback necessary to improve performance of later generations of controlled-release formulations and to identify those formulations best suited for further evaluation in outdoor tests.

CHEMICAL CONTROL TECHNOLOGY DEVELOPMENT

Fate of Fenac in the Aquatic Environment

by

Harish C. Sikka,* Edward J. Pack,* and Henry T. Appleton*

Introduction

The herbicide fenac (2,3,6-trichlorophenylacetic acid) has been found to be effective against submersed aquatic weeds including hydrilla. In order to evaluate the hazards associated with the use of fenac in the aquatic environment, it becomes important to study the environmental fate of the herbicide since its persistence, disappearance, or partial transformation will determine the degree of its hazardousness. Several physical, chemical, and biological factors determine the fate of a chemical in the aquatic environment. These include photodegradation, chemical hydrolysis, adsorption to sediment, microbial degradation, and bioaccumulation by aquatic organisms. Currently, very little is known about the effects of these factors on the persistence of fenac in the aquatic environment. This study was undertaken to assess the role of some of the processes which may determine the environmental behavior of fenac.

Photodegradation of Fenac

Procedure

The photodegradation of fenac in an aqueous solution was examined following irradiation with simulated sunlight. A 2-ppm solution of fenac in distilled water was irradiated with a 450-W Hanovia high-pressure mercury vapor lamp in a photochemical reactor manufactured by the Ace Glass Company. The reaction system consisted of a jacketed borosilicate glass vessel equipped with a side arm for withdrawing samples. A double-walled, water-cooled quartz well, housing the light source, was fitted into the vessel and immersed in the solution to be irradiated. The lamp was fitted with a Pyrex 7740 filter which excludes light of wavelength less than 280 nm. Aliquots of the photolyzed solution were withdrawn at appropriate intervals and analyzed for fenac. The samples were acidified to approximately pH 2 and extracted twice with diethyl ether. The combined ether extract was evaporated just to

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* Syracuse Research Corporation, Syracuse, New York.

dryness and the residue was dissolved in a suitable volume of hexane. The hexane solution was analyzed for the methyl ester of fenac by gas-liquid chromatography using an electron-capture detector. The methylated extract was also subjected to combined gas-liquid chromatography (GLC)-mass spectrometry to characterize the products resulting from the photodegradation of fenac.

Results

No loss of fenac was observed following 36 hr of irradiation at 300 nm in a photochemical reactor, suggesting that fenac is resistant to degradation by sunlight. It is known that the rate of photolysis of certain pesticides is considerably enhanced in the presence of naturally occurring photosensitizers. Since natural waters are known to contain photosensitizers, we conducted studies to determine whether fenac is degraded in the presence of known photosensitizers such as riboflavin phosphate (FMN). A 2-ppm solution of fenac in distilled water was irradiated in the presence of 100 mg FMN/ℓ. We noticed that the herbicide was readily photodegraded in the presence of FMN; more than 75 percent of the herbicide was lost after 24 hr of irradiation. These findings indicate that, although fenac is not readily photodegraded in distilled water, it may be degraded by the action of sunlight in natural waters due to the presence of naturally occurring photosensitizers.

On the basis of the mass spectral analysis, the compounds shown in Figure 1 were tentatively identified in the photolysate following irradiation of an aqueous solution of fenac in the presence of FMN.

Although light (300 nm) caused loss of fenac, it did not result in an extensive degradation of the molecule. Most of the degradation products included compounds in which only the side chain had been altered. Photolysis also resulted in dechlorination as indicated by the presence of two products in which one chlorine from the benzene ring had been removed. These results suggest that although photodegradation may cause an extensive dissipation of fenac in natural waters containing photosensitizers, the process may result in the formation of degradation products which may be relatively persistent.

Chemical Hydrolysis of Fenac

Procedures

Separate 250-ml samples of distilled water were buffered to pH 5.0 (0.01 M acetate) and pH 9.0 (0.01 M borate) and were autoclaved in Erlenmeyer flasks. Fenac was then added to the flask at a concentration of 2 ppm. The flasks were incubated in the dark at 10° and 22°C in an environmentally controlled chamber and maintained under sterile conditions. Aliquots of solution were withdrawn periodically and analyzed for fenac using the gas chromatographic procedure described earlier.

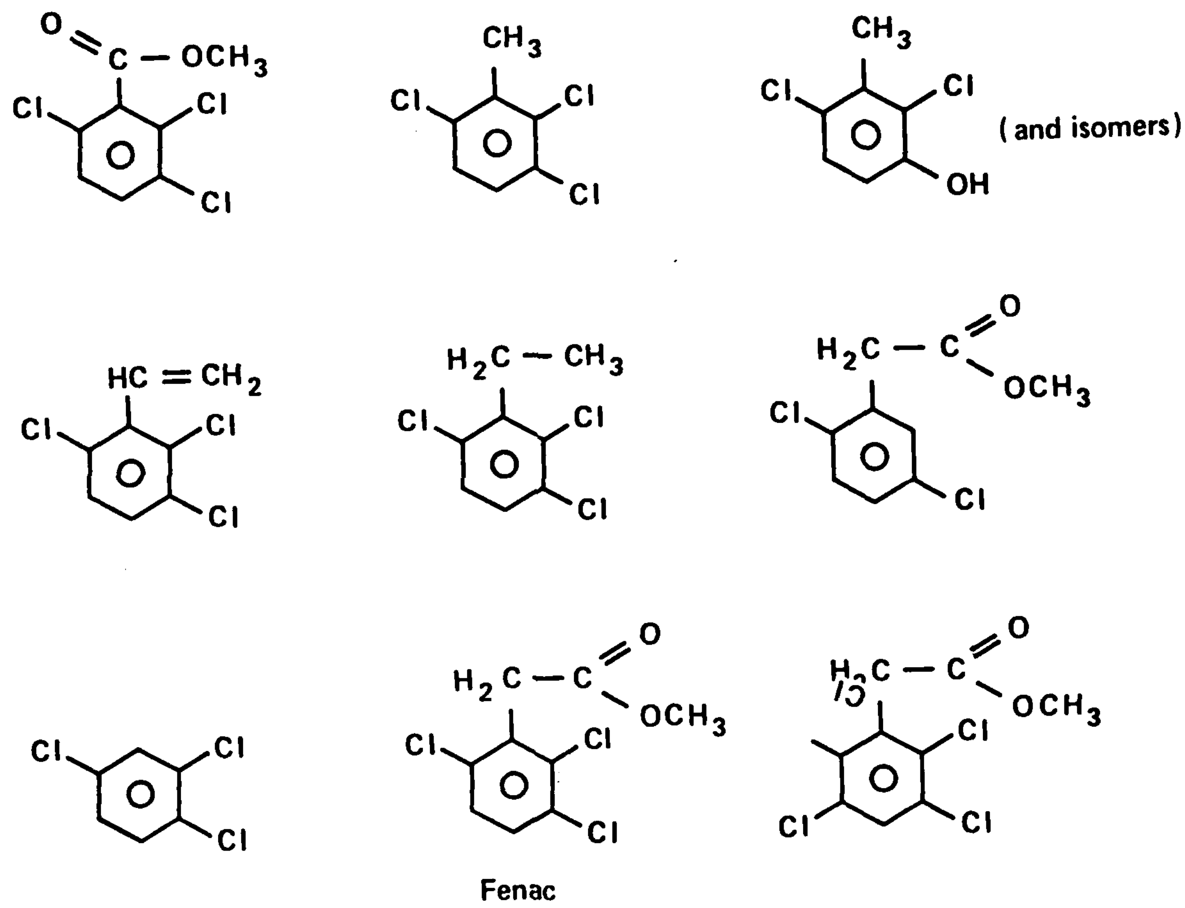

Figure 1. Proposed fenac photodegradation products

Results

Analysis of water samples after 7, 14, and 21 days of incubation did not indicate any loss of fenac, suggesting that the herbicide did not undergo hydrolysis during this period.

Adsorption of Fenac by Sediment

Procedures

These studies were done using four types of sediments (organic muck, reduced clay, unreduced clay, and sandy sediment) provided by WES. To determine the adsorption, 0.5 g sediment (dry-weight equivalent) and 50 ml of a 2-ppm solution of ^{14}C-fenac were added to an Erlenmeyer flask. The pH of the sediment suspension was 6.5. The flasks were shaken at ambient temperature (22°C) in the dark. Following the equilibration period (determined by measuring the disappearance of ^{14}C from the solution at various intervals over 24 hr), aliquots of the suspension were centrifuged at 12,000 × g and the clear supernatant was counted for ^{14}C. The amount of ^{14}C-fenac disappearing from the solution was assumed to be sorbed by the sediment. This amount was corrected for any loss of the ^{14}C-chemical due to sorption on the glassware. The degree of sorption was expressed as a distribution coefficient (K_d), the ratio of the amount of fenac adsorbed to the amount in equilibrium solution.

Results

Equilibrium studies at pH 6.5 revealed a fast initial uptake of fenac by the sediments. With all four sediments, maximum adsorption of the herbicide occurred within the first 5 hr. Subsequently, there was little or no change in the amount of fenac adsorbed. Therefore, all determinations were done after 24 hr of exposure.

Table 1 shows the amount of fenac adsorbed by the sediment and the K_d values. The results indicate that fenac is not adsorbed by the sediments in significant amounts. All the sediments tested showed a low capacity to remove fenac from the water as indicated by low K_d values. As expected, the sandy sediment adsorbed the least amount of fenac in comparison to the other sediments.

Table 1

Sorption of Fenac by Four Types of Sediment

Sediment	Fenac Adsorbed µg/g Sediment	K_d
Organic muck	6.3	3.3
Unreduced clay	11.4	6.0

(Continued)

Table 1 (Concluded)

Sediment	Fenac Adsorbed µg/g Sediment	K_d
Reduced clay	7.6	3.9
Sandy sediment	3.9	2.0

The effect of pH on the sorption of fenac by the sediments was also examined. With a change in pH of the solution, the relative proportion of the anionic and undissociated fenac species will change, which may affect the sorption of the herbicide by the sediment. In these experiments, 0.5 g sediment and 50 ml of a 2-ppm solution of ^{14}C-fenac in the appropriate buffer (0.05 M acetate, pH 4; 0.05 M borate, pH 9) were added to Erlenmeyer flasks and the sorption of the herbicide was determined as described above.

Table 2 shows the amount of fenac adsorbed by the sediment and the K_d values at 24 hr. The results indicate that fenac is not adsorbed at pH 6.5 and pH 9 in significant amounts. At pH 4, which approximates the pK of fenac (pK $\sim$ 3.7), adsorption was considerably increased in all the sediments except the sandy sediment. However, even at pH 4, the capacity of the sediments to adsorb fenac is considered to be low.

Table 2

Sorption of Fenac by Four Types of Sediment at Three pH's

	pH 4		pH 6.5		pH 9	
Sediment	Fenac Adsorbed µg/g Sediment	K_d	Fenac Adsorbed µg/g Sediment	K_d	Fenac Adsorbed µg/g Sediment	K_d
Organic muck	19.7	12.2	6.4	3.31	8.5	4.42
Unreduced clay	16.4	10.1	11.4	6.03	8.9	4.64
Reduced clay	24.8	15.5	7.6	3.95	8.0	4.18
Sandy sediment	6.9	4.68	3.9	2.01	8.3	4.35

Biodegradation of Fenac in Lake Water and Sediment

Procedure

Four 5-gal capacity glass aquaria containing 6 ℓ of lake water

and a 2-in. layer of sediment were placed in a constant temperature ($18^o \pm 1^oC$) chamber. The four types of sediments (organic muck, reduced clay, unreduced clay, and sandy sediment) used in these studies were provided by WES. After a 7-day equilibrium period, a stock solution of fenac was added to the aquaria so that the final concentration of fenac in the water was 2 ppm. The fenac solution was added to the water dropwise over a period of 2 hr to minimize disturbance of the sediment layer. The water was then gently stirred with a glass rod to ensure an even distribution of the herbicide throughout the water. Duplicate samples of water were taken at appropriate intervals and analyzed for fenac by GLC as described earlier. Distilled water was added to the aquaria weekly to maintain the level of water in the aquaria; fresh lake water was added every 4 weeks to ensure an active microbial population.

Results

The concentration of fenac in water samples taken at various times after treatment is shown in Figure 2. The dissipation of the herbicide from the water in various aquaria followed a similar pattern. During the first 6 weeks, extremely large variations in fenac concentration in water were noticed. Subsequently, the fenac levels in water showed considerably less fluctuations. After the fenac levels in water had somewhat stabilized, a gradual decrease in the concentration of the herbicide was observed. These findings suggest that fenac is not readily degraded by aquatic microorganisms.

Bioaccumulation of Fenac by Fish

These studies were carried out using two species of fish, e.g. bluegill sunfish and catfish.

Procedures

Bioconcentration of ^{14}C-fenac by bluegills was studied under dynamic, continuous-flow conditions. In this system, the dilution water was delivered with a peristaltic pump to a mixing chamber into which a syringe pump delivered a stock solution of ^{14}C-fenac in methanol (sp. activity 60 dpm/μg). The diluted exposure solution (averaging 1.36 ppm through the study) was conveyed to the exposure aquarium by gravity flow. The fish were exposed to water containing 1.36 ppm of ^{14}C-fenac. Periodically, the fish were removed from the exposure water and sacrificed, and the total ^{14}C content in the fish was determined by combusting in a Packard Tri-Carb sample oxidizer followed by liquid scintillation counting.

Studies on the bioaccumulation of fenac by catfish were conducted in two 20-gal aquaria each containing 6 kg of sandy loam and 40 ℓ of dechlorinated tap water. The ^{14}C-fenac (2,3,6-trichloro isomer) was added to the aquaria at a concentration of 2 ppm. After adding fenac, the water was stirred and samples of water and sediment were taken and

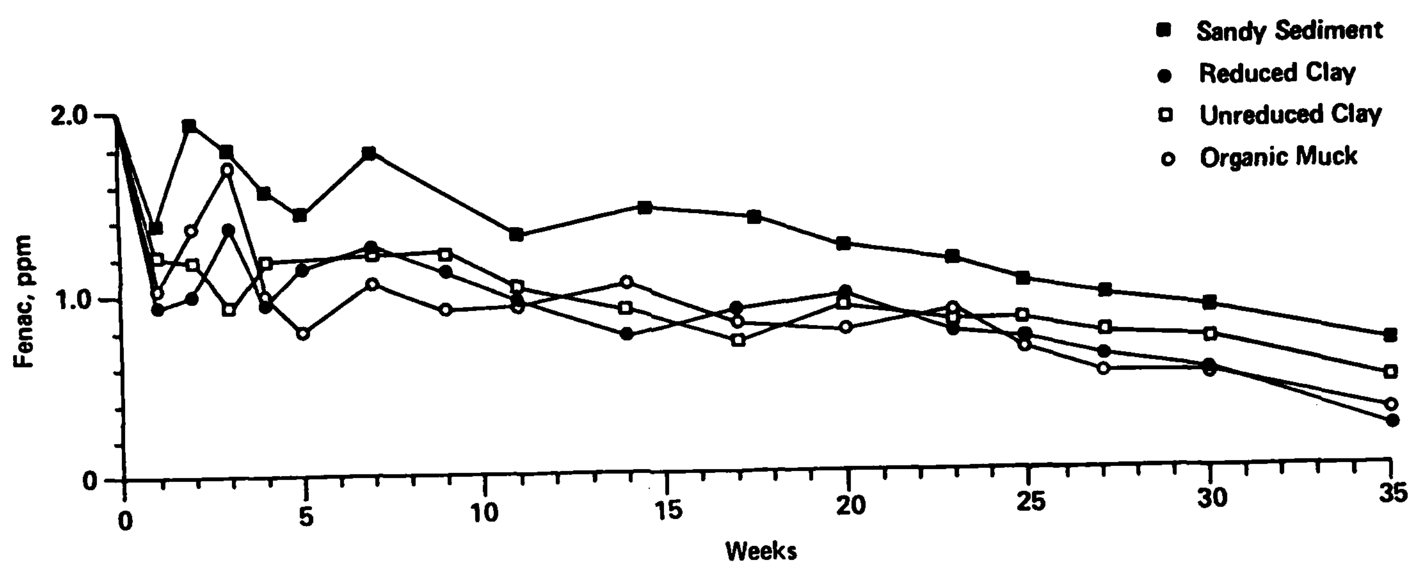

Figure 2. Fenac residues in water of 5-gal aquaria treated with 2 ppm of the herbicide

counted for total ^{14}C. After a 30-day aging period, catfish were added to each aquarium. Prior to introducing fish, aliquots of water and sediment were taken and counted for total radioactivity. The water samples were also extracted with diethyl ether following acidification and the ether extract was analyzed for fenac by gas chromatography using an electron-capture detector.

The fish and water samples were taken 1, 3, 7, 14, and 21 days after introducing the fish into the aquaria. The fish were separated into head, viscera, and edible flesh portions and the amount of radioactivity in fish tissues was determined by combusting them in a Packard Tri-Carb sample oxidizer followed by liquid scintillation counting.

Results

Bluegill sunfish. The concentration of ^{14}C-residues in bluegills exposed to 1.36 ppm of ^{14}C-fenac is shown in Table 3. At equilibrium (120 to 240 hr of exposure), bioconcentration factors of 8.3 in edible tissue and 10.1 in nonedible tissue were achieved. These results indicate that fenac does not bioaccumulate to a significant extent in fish.

Table 3

Bioconcentration of ^{14}C-Fenac by Bluegills

Exposure hr	Tissue Fraction	^{14}C-Fenac Equivalent, ppm* Fish Tissue	Water	Bioconcentration Factor**
24	Edible	7.50 ± 0.67	1.30	5.77
	Nonedible	10.69 ± 1.51		8.22
72	Edible	8.89 ± 0.40	1.32	6.73
	Nonedible	13.73 ± 0.32		10.40
120	Edible	12.07 ± 0.14	1.42	8.50
	Nonedible	16.49 ± 0.76		11.61
168	Edible	11.20 ± 0.09	1.38	8.12
	Nonedible	9.99 ± 1.64		7.24
240	Edible	11.43 ± 0.65	1.40	8.16
	Nonedible	15.886 ± 0.02		11.35

* Values are the average of duplicate analyses, with two fish per analysis.

** Bioconcentration factor = ppm ^{14}C in fish/ppm ^{14}C in water.

Catfish. During the 30-day aging period, the level of ^{14}C-fenac in water remained relatively constant. After adding the fish, the level of total radioactivity in the water showed little variation between

sampling dates over a 21-day period. The ^{14}C-material in the water (through 21 days after adding the fish) was found to be fenac as determined by EC-GLC analysis.

The levels of ^{14}C in catfish at various times after exposure to ^{14}C-fenac are shown in Table 4. The ^{14}C-residue data shown in Table 4 are based on the total level of ^{14}C in the fish obtained by combusting the fish exposed to ^{14}C-fenac and counting the resulting $^{14}CO_2$. The absolute levels of fenac in the fish were not determined due to low levels of ^{14}C residues. The results clearly show that the uptake of fenac by the fish is quite low. The concentration of ^{14}C residues (^{14}C-fenac equivalents) in the fish was less than that in the ambient water and appeared to have reached equilibrium within 24 hr after adding the fish. These results confirm the earlier findings that fenac does not bioaccumulate in fish to a significant extent.

Table 4

Uptake of ^{14}C-Fenac by Catfish*

Days (After Introducing Fish)	Tank	^{14}C-Fenac Equivalent, grams Wet Weight			
		Whole Fish	Viscera	Head	Edible Flesh
1	1	0.40	0.86	0.67	0.40
1	2	0.29	0.40	0.29	0.33
3	1	0.20	0.78	0.35	0.36
3	2	0.35	0.72	0.34	0.32
7	1	0.29	0.50	0.28	0.24
7	2	0.17	0.64	0.10	0.14
10	1	0.42	0.81	0.46	0.31
10	2	0.19	0.64	0.10	0.14
14	1	0.33	0.82	0.33	0.28
14	2	0.17	0.43	0.08	0.20
21	1	0.26	1.20	0.11	0.25
21	2	0.17	0.42	0.09	0.175

* Values are the average of duplicate analysis, with two fish per analysis.

Conclusion

On the basis of the results of these studies, it appears that the biological and nonbiological processes examined in this investigation are not likely to influence the environmental fate of fenac. The herbicide is expected to persist in an aquatic ecosystem because of its resistance to biological and nonbiological degradation. However, in spite of its tendency to persist, fenac may not present an environmental hazard because of its low potential for bioaccumulation and low toxicity to aquatic organisms.

BIOLOGICAL CONTROL TECHNOLOGY DEVELOPMENT

An Overview

by

D. R. Sanders, Sr.*

Introduction

Objective

As stated in the 5-year plan, the overall objective of the Biological Control Technology Development element of the Aquatic Plant Control Research Program (APCRP) is to provide the operational capability to use biological agents for control of problem aquatic plants in the shortest time possible. This includes insects, plant pathogens (fungi and bacteria), and herbivorous fishes. The Wetland and Terrestrial Habitat Group of the U. S. Army Engineer Waterways Experiment Station (WES) Environmental Laboratory has been given the responsibility for directing all aspects of this program element of the APCRP, except for research related to herbivorous fishes.

Approach

The approach to the eventual use of a biological agent for the control of aquatic plants has traditionally consisted of four distinct tasks. The first of these involves the search and discovery of candidate biocontrol agents. Because most of the troublesome aquatic plant species are exotics, many of the searches have been conducted in the countries of their origin. The second task involves an elaborate testing program aimed at determining host specificity and potential for control. This usually involves preliminary studies in the country of origin, followed by more detailed host specificity studies in quarantine in the United States. The third major task involves compilation of a data package to support a petition for the field release of the candidate biocontrol agent. No exotic organism can be released in the United States without approval of the joint U. S. Department of Agriculture (USDA)-U. S. Department of the Interior (USDI) Working Group for the Biological Control of Weeds. In some cases, the Working Group may require additional data prior to approval of the release. After approval for release has been obtained, the fourth major task involves the successful establishment of the biocontrol agent in the field. This may require some rather basic studies, such as determination of the

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* U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

appropriate methods for release and the best time for release to ensure successful establishment.

As was the case with the insects *Agasicles*, *Vogtia*, and *Amnyothrips* for the control of alligatorweed (*Alternanthera philoxeroides* (Mart.) Griseb.), such a program can effectively be used to significantly reduce the problem level of a target aquatic plant. However, the failure of the insects to control alligatorweed at the northern fringe of the alligatorweed range and the recent significant increase in the alligatorweed population in areas where the plant was previously controlled by the insects, suggests that perhaps we need to know more about how to effectively manage biocontrol agents. This suggests a need for a fifth major task in the overall technology development process. It involves the development of specific management techniques aimed at increasing the effectiveness of the biocontrol agents. Population development and dynamics of the biocontrol agent and the target plant in the various geographic areas must be studied to determine the conditions under which restocking of the biocontrol agent is desirable or necessary. Also, the potential for enhancement of a biocontrol agent by its combination with other organisms or inorganic agents must be elucidated.

Current Studies

Studies currently in progress as part of the biological control technology development element of the APCRP address each of the five identified areas or tasks identified above. Approximately 20 species of arthropods and fungi are being investigated at some level for potential as biocontrol agents of aquatic plants. Most of this work is being conducted by contract. These projects are discussed in detail in the subsequent papers. Some projects being conducted partially as in-house efforts are discussed below.

Cold-hardy *Agasicles*

Early in 1979, Dr. Gary Buckingham of the USDA-SEA Quarantine Laboratory, Gainesville, Fla., collected a colony of *Agasicles hygrophila* from the coldest portion of its range in Argentina and brought it to the Quarantine Laboratory at Gainesville. After a period in quarantine to check for parasites and diseases, the colony was ready to be placed in the field. Personnel from WES coordinated the field releases in North Carolina, South Carolina, and northern Alabama. Development of field populations will be closely monitored through the FY 80 growing season and a decision will be made on the benefits to be derived by placing the cold-hardy strain in other areas.

Parapoynx (=Nymphula) rugosalis

While conducting other studies in the Panama Canal Zone in 1978, Mr. Russell F. Theriot and I discovered a moth on hydrilla that appeared to be producing large open areas in otherwise uniform hydrilla mats. Specimens were brought to the United States for positive identification.

Subsequently, we arranged for and assisted Drs. Ted Center and Joseph Balciunas of the USDA-SEA Aquatic Plant Management Laboratory, Fort Lauderdale, Fla., in the conduct of preliminary feeding studies in the Panama Canal Zone designed to support a petition for importation of *P. rugosalis* into quarantine in the United States. The initial petition was rejected by the USDA-USDI Working Group due to a lack of basic information regarding *P. rugosalis*. Additional efforts will be made to obtain the data required to introduce *P. rugosalis* into quarantine.

Other in-house research

Other in-house research pertains to the Large-Scale Operation Management Test in Louisiana and the Panama Canal Project. These studies will also be discussed in subsequent papers.

New Research Projects

Three new biocontrol research projects have already been, or will be, initiated in FY 80. These include:

a. Domestic survey for plant pathogens of Eurasian watermilfoil (contract).

b. Microbiological control of Eurasian watermilfoil by induction of lytic enzymes in normally symbiotic microbes of the rhizosphere (contract).

c. Effects of temperature on the survival and overwintering ability of *Sameodes albiguttalis* (in-house).

BIOLOGICAL CONTROL TECHNOLOGY DEVELOPMENT

Evaluation of Two Native Insects for Control of Eurasian Watermilfoil

by

Gary R. Buckingham*

Although Eurasian watermilfoil, *Myriophyllum spicatum* L., is considered an introduced species, it is part of a complex of closely related species, two of which are native to North America. Native insects which attack these other two species or other milfoils can be considered for use against *M. spicatum*. There are, however, only a few insect species reported attacking the milfoils in North America. These include about four species of moths and six species of weevils. A few midges and caddisflies have also been associated with milfoils but their feeding habits are not well understood. Since there have been no foreign candidates ready for introduction into quarantine, two native insects have been studied at the Gainesville quarantine of the Division of Plant Industry, Florida Department of Agriculture.

Weevil

The first of these is a small weevil, *Litodactylus leucogaster* (Marsham), which occurs both in Europe and in North America. The North American examples were previously known as *Phytobius griseomicans* Schwarz. This led to earlier unsuccessful attempts to import the European species, *L. leucogaster*, into quarantine from Yugoslavia since Lekic and Mihajlovic (1970)** had stated that it had potential for destruction of the seed. The laboratory colony was collected near San Francisco, California, at a location suggested by Dr. Charles O'Brien, of Florida A&M University. This species occurs mostly in the northern states and Canada. Locations in California and Georgia probably represent recent introductions along with *M. spicatum*.

The adult weevil is about 2.7 mm long. It is gray to brown dorsally but yellowish on the sides and ventrally. It has a white central patch at the front of the elytra. It can be easily distinguished from

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* Biological Pest Control Research Unit, U. S. Department of Agriculture, Gainesville, Florida.

** Lekic, M., and L. Mihajlovic. 1970. Entomofauna of *Myriophyllum spicatum* L. (Halorrhagidaceae) as an aquatic weed in Yugoslavia. J. Sci. Agr. Res. 82:63-76.

related weevils by the paired acute pronotal tubercles and by the distinctly raised fifth strial intervals on the elytra. The eggs of *L. leucogaster* are generally desposited in the ovaries which have been eaten out by the females or among the buds. From 7 to 15 eggs per day are deposited over a 1- to 2-month period for a maximum of over 700 eggs per female. They hatch after 3 to 4 days. The newly emerged larvae feed inside the buds or ovaries; when they are larger they feed externally on the flowers and stems. The large larvae are pink or reddish and generally encircle the stem while feeding. The complete larval period lasts about 8 to 10 days in the laboratory.

The mature larva enters the water and forms a cocoon in an excavation in the stem. The brown cocoon is spherical but since half of it lies in the stem it appears to be hemispherical. It is filled with air from the stem and if the stem becomes waterlogged so does the cocoon and the pupa dies. The total time in the cocoon is from 5 to 8 days with an actual pupal period of 2 to 4 days. These durations are for insects reared in the laboratory at about 24° to 25°C constant temperature and would probably be longer for field populations.

Adults overwinter among litter and milfoil strands on the shore and then move in the spring to the emersed flowers. Most activity occurs on the flowers, but they will readily crawl into the water when disturbed and they often rest underwater. They are able to survive at least 7 hr when forcibly sumbersed since they breathe from an air bubble which surrounds their body. Some feeding occurs on the stems or buds just below the surface but most of it is on the emersed flowers, buds, and flower stalks. Heavy feeding can completely destroy the flowers or can cut the flower stalk so that it falls over and nothing develops. Individual females eat approximately 7 to 20 flowers per day. They appear to be good fliers so that they should have good dispersal, at least locally.

The only known host plants of *L. leucogaster* are *M. spicatum, M. exalbescens* Fernald., and *M. verticillatum* L. These three species are so close taxonomically that *L. leucogaster* can almost be considered monophagous. In laboratory tests we were able to obtain eggs from females reared on parrotfeather, *Myriophyllum aquaticum* (Vell.) Verdc., and a few of the resulting larvae formed cocoons; however, even with this other milfoil, we were only successful after trying various rearing techniques over a 2-year period. Some starvation feeding occurred on mermaidweed, *Proserpinaca*, which is in the same family as milfoil, Haloragaceae, but no eggs were formed nor were larvae able to survive. Almost no starvation feeding occurred on flowers of *Potamogeton* which are similar in appearance to those of milfoil but which are not similar taxonomically. Appreciable feeding was found only on several species of *Polygonum*. This might seem surprising since the relationship between *Polygonum* and milfoil is quite distant, but it was not surprising and was expected since the most common host plant of the weevil relatives is *Polygonum*. Like its relatives, *L. leucogaster* will eat and obtain

energy from *Polygonum* but unlike them it does not produce eggs nor oviposit and the larvae do not feed. This same situation occurs in Pakistan where another milfoil weevil overwinters on *Polygonum* but does not reproduce on it (Habib-Ur-Rehman et al. 1969).*

On 22 August 1979, Mr. Russell Theriot, WES, Dr. Joe Balciunas, University of Florida, and I released 187 mixed adults and 100 eggs at Crystal River, Florida. We recovered one female at least 100 m from the original release site indicating a rapid dispersal of the released adults. Two males were recovered on 8 November about 2.6 km from the release site indicating reproduction and dispersal. Flowers are present at Crystal River from June to mid-November; therefore, if the weevils can survive the winter, they have the potential for rapid buildup next year. Another native weevil, *Perenthis vestitus* Dietz., is already present at Crystal River so that *L. leucogaster* will have competition. We have studied this competition in laboratory cages but the results are inconclusive.

Since we have not studied field populations of *L. leucogaster,* it is impossible to predict its potential impact upon seed production. At Crystal River the mat produces about 120 to 150 flowers per square metre in the heaviest flowering areas and 50 to 80 flowers per square metre in the moderate areas. Large areas at any one time have almost no flowers, and these areas change throughout the season as the flowering progresses from shore outwards and then back again. In laboratory pool studies, flowers were emersed for only about 8 to 10 days. The large numbers of flowers and the short time period that each is available suggest that, even with a large weevil population, a great number of seeds will still escape attack. However, since the role of seeds in the population dynamics and spread of this plant is unknown, we can only assume that some reduction of the seed is more preferable to aquatic weed managers than no reduction. There is also a chance that a pathogen might be found which would be able to invade the plant through the weevil damage or could be mechanically transmitted.

Moth

The second insect studied is a small moth, *Acentropus niveus* (Olivier). This moth is either native or else was naturalized from Europe. Its biology has been well studied in Europe and Dr. Suzanne Batra (1977)** USDA, Beltsville, Maryland, has studied it in the field

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* Habib-Ur-Rehman, M. Mushtaque, G. M. Baloch, and M. A. Ghani. 1969. Preliminary observations on the biological control of water-milfoils (*Myriophyllum* spp.-Haloragidaceae). C.I.B.C. Tech. Bull. 11:165-171.

** Batra, S. W. T. 1977. Bionomics of the aquatic moth, *Acentropus niveus* (Olivier), a potential biological control agent for Eurasian watermilfoil and hydrilla. New York Entomol. Soc. 85(3):143-152.

in New York and in the laboratory. Dr. Batra concluded that it had potential for use against milfoil and hydrilla but needed further host specificity studies. The normal female is a small gray moth, about 5 mm long, with greatly reduced wings. We have recovered only flightless females in our rearings from the St. Lawrence River, New York, but recently Dr. Batra reared a winged female from there. These flightless females emerge from their cocoons to the water's surface where they attract the flying males which are light gray to almost white. After mating the females enter the water and deposit a mass of yellowish eggs on a leaf. The eggs hatch after about 11 days. The newly emerged larvae bore into the stems and the older larvae construct loose cases from the leaves. They leave their cases when feeding and then construct new ones so that a majority of the cases are empty at any one time. Counting the cases on milfoil plants and not the actual larvae thus gives a large overestimate of the population. A tightly woven cocoon is formed on the stem and, like that of *L. leucogaster*, it receives air from the stem. Waterlogged stems or even stems which are too short will cause death of the pupa. In New York they overwinter as large larvae in tightly woven cases. In our laboratory at long light and 22°C they have had continuous generations. The literature indicates that there is only one generation per year both in Europe and North America but I would not be surprised if there are two generations in shallow areas. Our laboratory generations take about 3 months. At constant temperatures of 25°C and above the larvae do not seem to develop. This species is extremely difficult to colonize and as far as I am aware no one else has colonized it. The published biologies have been studied by bringing field material into the laboratory. Even our colony has been a touch-and-go situation so that our studies have been severely limited. Adult emergence occurs sporadically over a long period so that it is difficult to have sufficient numbers for successful mating.

Dr. Batra (1977)* lists six host plants in Europe and an additional three in North America plus hydrilla in the laboratory. These hosts include *Ceratophyllum*, *Elodea*, and *Potamogeton*. In fact, it appears from the literature that *Ceratophyllum* might be a more common host than milfoil. We have obtained feeding by large larvae on *Ceratophyllum*, *Najas*, *Potamogeton*, and *Hydrilla* even when in the presence of milfoil. We have not had sufficient larval material to compare total amounts eaten in various situations, but in aquaria they feed readily on all of them. Although feeding on these other species does not mean that a population can develop on them, we have now reared larvae from egg to medium size on *Potamogeton*. Since we had previously reared small field-collected larvae to adult on *Potamogeton*, there is no doubt that it is a true host plant. *Acentropus*, like most if not all the other aquatic Lepidoptera which attack macrophytes, is not specific and its potential use is dependent upon acceptance of damage to the other plants. Since these plant species are often considered weedy when in large stands, this lack

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* <u>Ibid</u>.

of specificity may not be that important in many situations. Since the females are wingless, they would not disperse rapidly from a large population buildup on a weedmat to areas where the plants were at desirable levels, except possibly in a fast-flowing river. This lack of mobility and their long generation time would probably keep them from causing much damage in areas of normal plant populations. If large mats of *Potamogeton* or other species were used for feeding wild ducks, the duck feeding probably would be sufficiently devastating to the *Acentropus* that it would not be able to build up a large population.

The same two factors, long generation time and low female mobility, which should keep this species from becoming a problem when plants are at low densities, will probably also prevent it from being an effective biocontrol agent.

BIOLOGICAL CONTROL TECHNOLOGY DEVELOPMENT

Biological Control of Waterhyacinth, Hydrilla, and Eurasian Watermilfoil

by

T. D. Center* and J. K. Balciunas*

Project A. Release and establishment of *Sameodes albiguttalis*; monitor dispersal; evaluate efficacy.

Objectives

The purpose of this project is the release and establishment of *Sameodes albiguttalis* at selected field sites so as to develop an appropriate methodology for use in waterhyacinth management. Once the populations have become established and have dispersed throughout Florida, emphasis will shift towards evaluating the efficacy of this insect for waterhyacinth control.

Approach

Releases of *S. albiguttalis* were made between October 1977 and June 1978. The sites were located primarily in south Florida at ca. 26° N latitude. They were continually monitored for signs of establishment and dispersal. Once localized dispersal was evident, check points north of the release area were repeatedly monitored until it was determined that the insect had moved across the intervening distance. These check points were continually moved northward ahead of the advancing insect population front and the rates of dispersal estimated from the time required for the population to move a known distance. Efficacy will be evaluated based upon changes in various characteristics of the plant population following the establishment of this insect at specific sites.

Current Status

Sameodes has been released at a total of 20 sites and has

* Aquatic Plant Management Laboratory, U. S. Department of Agriculture, Fort Lauderdale, Florida.

established at 17 of these. We have found the type of plant present in the release site to be a critical factor for the successful establishment of the insect. A distinct preference is apparent for plants with characteristics of luxurient growth, i.e. stout petioles, reinform laminae, and a generally robust form. Populations do not readily become established on plants with spindly petioles, short leaves, and lanceolete laminae which are characteristic of less than optimum growing conditions. Populations have dispersed ca. 200 miles to the north and we have estimated the dispersal rate at ca. 35 km per month.

Significant Accomplishments

Procedures for developing, handling, and maintaining a laboratory colony of *S. albiguttalis* have been perfected. Populations have been established at 17 of 20 release sites from the release of over 80,000 individuals. Populations have begun to disperse and preliminary estimates of dispersal rates have been obtained. Releases have been evaluated in terms of the quantity released, season in which the releases were made, and the morphological condition of the plants in the release sites. The latter has been found to be the most important factor to be considered in a release strategem for waterhyacinth management.

Project B. Domestic survey of insects on *Hydrilla verticillata* and *Myriophyllum spicatum*.

Objectives

The objectives of this survey are (a) to provide quantified lists of insects associated with each of these two submersed weeds, and (b) to determine which of these species are damaging these weeds and, when possible, the extent of damage and controlling factors.

Approach

Samples of these weeds are collected with a rake or an anchor and placed in a plastic bag. These samples are placed on ice during transportation back to the Fort Lauderdale laboratory where they are frozen. Technicians then examine each piece of plant material under a dissecting microscope, rate the degree of herbivore damage observed, and remove all the fauna for subsequent identification. Most of the Florida samples are done on a quantitative basis utilizing a specially constructed sampler. Depth, water temperature, salinity, conductivity, and secchi disc transparency are recorded at the sampling point whenever possible. In order

to be able to determine what other weeds are attacked by the herbivores collected, other submersed weeds in the sampling vicinity are also collected using the procedures outlined.

Current Status

As of the end of November 1979, 58 collections of Eurasian watermilfoil and its associated fauna have been made from the states of Alabama, California, Florida, Georgia, Louisiana, New York, Oklahoma, Tennessee, Texas, Washington, and Wisconsin. Additional collections of related species of milfoil and other submersed plants were also made in several South Carolina locations. Preliminary compilation of the data from the samples processed so far indicates that only a few groups of insects associated with Eurasian watermilfoil damage it. The most commonly encountered are the larvae of the midge (Diptera:Chironomidae) and of caddisflies (Trichoptera). However, the direct damage to the milfoil caused by the activities of these insects appears to be relatively minor.

The most intensive herbivore damage to Eurasian watermilfoil observed so far is caused by the feeding of the aquatic larvae of the moth *Acentropus niveus*. However, these larvae also feed on a variety of other aquatic plants and their populations seldom build up to a level where the damage is readily discernible from the surface. Four species of weevils (Coleoptera:Curculionidae) have been collected from the flowers of *M. spicatum.* Several of these appear to severely damage the flowers and to significantly reduce seed production. We are cooperating with Dr. Gary Buckingham (USDA) of Gainesville to monitor the release and establishment of the weevil *Litodactylus leucogaster* at Crystal River, Florida.

To date, 198 collections of hydrilla and its fauna have been made. Fifteen of the sample sites are in California, Georgia, Louisiana, Texas, and the Panama Canal Zone; the rest are in 17 counties in Florida. As with Eurasian milfoil, the insect damage to hydrilla is restricted to a few groups. Midge larvae are common and in a few locations extremely abundant (several dozen on or in each hydrilla stem). When present at these high densities, direct damage, such as fragmentation of stems, is observable but at most locations the direct damage appears insignificant. Several species of caddisfly larvae consume hydrilla for food and as material for their cases. At most places their population levels are low and extensive damage to hydrilla caused by Trichoptera has not been observed. The most severe insect damage to hydrilla observed was caused by the aquatic larvae of several species of moths. In the Panama Canal Zone, large areas defoliated by dense populations of the larvae of *Parapoynx rugosalis* (Lepidoptera:Pyralidae) are apparent in the hydrilla mat. In Florida, the larvae of *Parapoynx diminutalis* reached an extremely high population level at Lake Lochloosa, and many acres of hydrilla appeared from the surface to be almost completely defoliated.

From this survey, it is clear that *P. diminutalis* is rapidly expanding its range in Florida and in several areas populations have reached damaging levels.

It should be noted that while the direct damage caused by midge larvae on both milfoil and hydrilla is not unusually severe, the damage caused by pathogens associated with excavations of chironomid larvae could be considerable. Among the pathogens of *M. spicatum* isolated by Dr. John Andrews, University of Wisconsin, is one which is frequently associated with midge larvae damage.* Infestations of *M. spicatum* in Wisconsin have decreased dramatically within the last few years and this may be part of the cause. Decline of hydrilla at Orange Lake, Florida; Lake Conroe, Texas; and Lake Seminole, Georgia, was accompanied by high population levels of midge larvae. We believe this insect-pathogen link should be more thoroughly investigated.

Significant Accomplishments

A sampler has been designed and constructed which can be operated by a single person to obtain quantitative samples of submersed weeds and their associated fauna. Over 350 samples of submersed plants and their associated fauna have been collected. Preliminary host specificity evaluations of *P. rugosalsis* have been conducted. Extensive range extensions of *P. diminutalis* have been documented and significant levels of damage to hydrilla by the larvae have become apparent at some locations.

Project C. Foreign Exploration for Natural Enemies of *Hydrilla verticillata* and *Myriophyllum spicatum*.

Objectives

The purpose of this project is to thoroughly explore the native ranges of hydrilla and Eurasian watermilfoil in the hopes of discovering potential biological control agents for use in the United States.

Approach

Cooperative projects are negotiated with foreign agencies to survey the target weeds within areas of specific interest.

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* Personal communication, Dr. John Andrews, University of Wisconsin, Madison, Wisconsin.

Current Status

A project with the Commonwealth Institute of Biological Control (CIBC) has been agreed upon to survey hydrilla in Africa. Work will begin when they have completed building their station in Muguga, Kenya. Negotiations are now underway for a similar project with Queensland Agricultural College for an Australian survey.

Significant Accomplishments

Negotiations have been completed and a cooperative agreement finalized with CIBC for a 1-year hydrilla survey in Africa. Completion of this work is tentatively set for September 1981.

BIOLOGICAL CONTROL TECHNOLOGY DEVELOPMENT

Studies on Laboratory Rearing and Natural Populations of *Arzama densa*

by

R. G. Baer* and P. C. Quimby, Jr.*

Waterhyacinth [*Eichhornia crassipes* (Mart.) Solms] is a perennial, herbaceous, floating freshwater weed. It contributes to problems concerning agriculture, navigation, and public health and presently infests about 1 million acres of water bodies which include rivers, canals, streams, reservoirs, and coastline areas of the southeastern United States.

Previous studies on the life history of the native moth, *Arzama densa* Wlk, have indicated that the larvae severely damage waterhyacinth (Vogel and Oliver 1969a, 1969b; Center 1975, 1976). Therefore, these present studies were initiated to determine the feasibility of mass-rearing sufficient numbers of these insects for release to augment the natural population. Behavior of naturally occurring populations of this insect species was studied at Venice, La. Insect material for this project was also collected from this location.

Some field-collected larvae were placed directly on an artificial diet which in part consisted of freeze-dried waterhyacinth. A range of 31 to 81 percent of diet-fed larvae completed development to normal adults. Other larvae supplied daily with fresh cut plant material failed to complete development to normal adults.

Adult moths were mated in oviposition cages (designed by J. M. McWilliams for mass-rearing *Heliothis* spp., USDA, Stoneville, Miss.). Eggs were sterilized and placed on the diet. Developing larvae were changed to a new diet after the third, fifth, and sixth molt.

Developmental time (egg to adult) averaged 91 days, ranging from 73 to 163 days. Two laboratory generations were successfully reared on the diet. Sixty-three percent of the F_1 generation and eleven percent of the F_2 generation completed their development. Mating studies indicate a trend towards reduced fecundity in the F_2 generation. Comparisons of pupal weights indicated that diet-fed individuals were as large or larger than those collected in the field. These heavier pupae may be an indication of dietary imbalance as compared to normal plant food. Modifications of the diet are presently being evaluated.

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* Southern Weed Science Laboratory, U. S. Department of Agriculture, Stoneville, Mississippi.

Natural enemies were found to play important roles in checking the populations of *A. densa*. Parasitism by a wasp, *Campoletis* sp. nr. *oxylus* (Cress), and a fly, *Lydella radicis* Townsend, were the most abundant natural enemies. Field studies suggested that natural populations of *A. densa* could be supplemented with laboratory individuals but would probably be most effective during July and the beginning of August when parasite populations are low.

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BIOLOGICAL CONTROL TECHNOLOGY DEVELOPMENT

Biological Control of Waterhyacinth and Hydrilla Using Plant Pathogens

by

T. E. Freeman,* R. Charudattan,* and R. E. Cullen*

The objectives of this study are to search for, evaluate, and ultimately utilize plant pathogens in a biological control program for aquatic weeds. Our efforts during the past year have been directed toward attaining this goal. They have been concentrated primarily on two pathogens that appear most promising for control of waterhyacinth and hydrilla. They are: *Cercospora rodmanii* for control of waterhyacinth and a Dutch isolate of *Fusarium roseum* 'Culmorum' for control of hydrilla.

Cercospora rodmanii

This fungus is believed to have caused a severe decline of waterhyacinths in Rodman Reservoir in 1971 and to a lesser extent in 1972 and 1973. In this latter year, it was isolated from diseased plants in Rodman Reservoir by Dr. K. E. Conway. The fungus was established as a new species and named *Cercospora rodmanii* after the location of its discovery. Tests in both Florida and Louisiana have shown it to have a high potential as a biocontrol of waterhyacinths. Subsequently, the University of Florida has patented the fungus for such purposes and has made an agreement with Abbott Laboratories to produce it in product form.

We have cooperated with Abbott and the Army Corps of Engineers in evaluating this product form. Tests conducted in small pools at Gainesville show the dry product form to be as effective in inducing infection as fresh inoculum of the fungus grown in our laboratory. These results were verified by the Army Corps in tests conducted at WES and at field sites in Louisiana. These results, along with toxicological data, will be utilized to petition for an experimental use permit from EPA. They will also form the basis for a Large-Scale Operational Management Test (LSOMT) in Louisiana conducted by WES and Abbott. By early 1980 we hope to conduct a similar type test in Florida along the St. Johns River watershed and other selected sites. In this regard, in October 1979 we established an observation-type test of *C. rodmanii* in a small isolated pond near Gainesville.

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In addition to the various field tests of effectiveness of *C. rodmanii* for control of waterhyacinth, several other studies have been conducted. These have concerned cultural, histological, and epidemiological aspects of the pathogen and the disease it incites. These are summarized in Table 1. Histological aspects of the fungus as it occurs on the plant are shown in Figures 1 and 2.

Table 1

Characteristics of *Cercospora rodmanii*

Infection	
Infective propogule	Mycelium and either primary or secondary spores
Mode of infection	Through stomates
Cultural characteristics	
Optimum temperature	Near 25°C
Range of good growth	20° to 30°C
Growth at body temperature (37.1°C)	None
Survival at 37.1°C	At least 2 weeks
Best medium (solid or liquid)	Potato dextrose agar or broth (fresh or Difco brand) plus 0.5 percent yeast extract
Growth on defined medium	Yes (Czapek-Dox)
Variation in culture	Some sectoring, especially for pigmentation
Sporulation	Increased by ultraviolet light
Morphology	
Spore size (range)	84 to 284 by 3 to 5 nm
Spore septation	Multiseptate
Spore shape	Acicular, truncate base
Spore color	Hyline
Conidiophores	In fasciles of 3 to 12 emerging through stomates, brown
Epidemiology	
Spore production	Nil below 10°C
Monthly variation in spores	Maximum, October; minimum, January
Maximum No. spores trapped (1 day)	498 m^3 of air
Biocontrol potential	High

Note: For a complete description of *C. rodmanii* see Conway, K. E. 1976. Canad. J. Bot. 54:1079-1083.

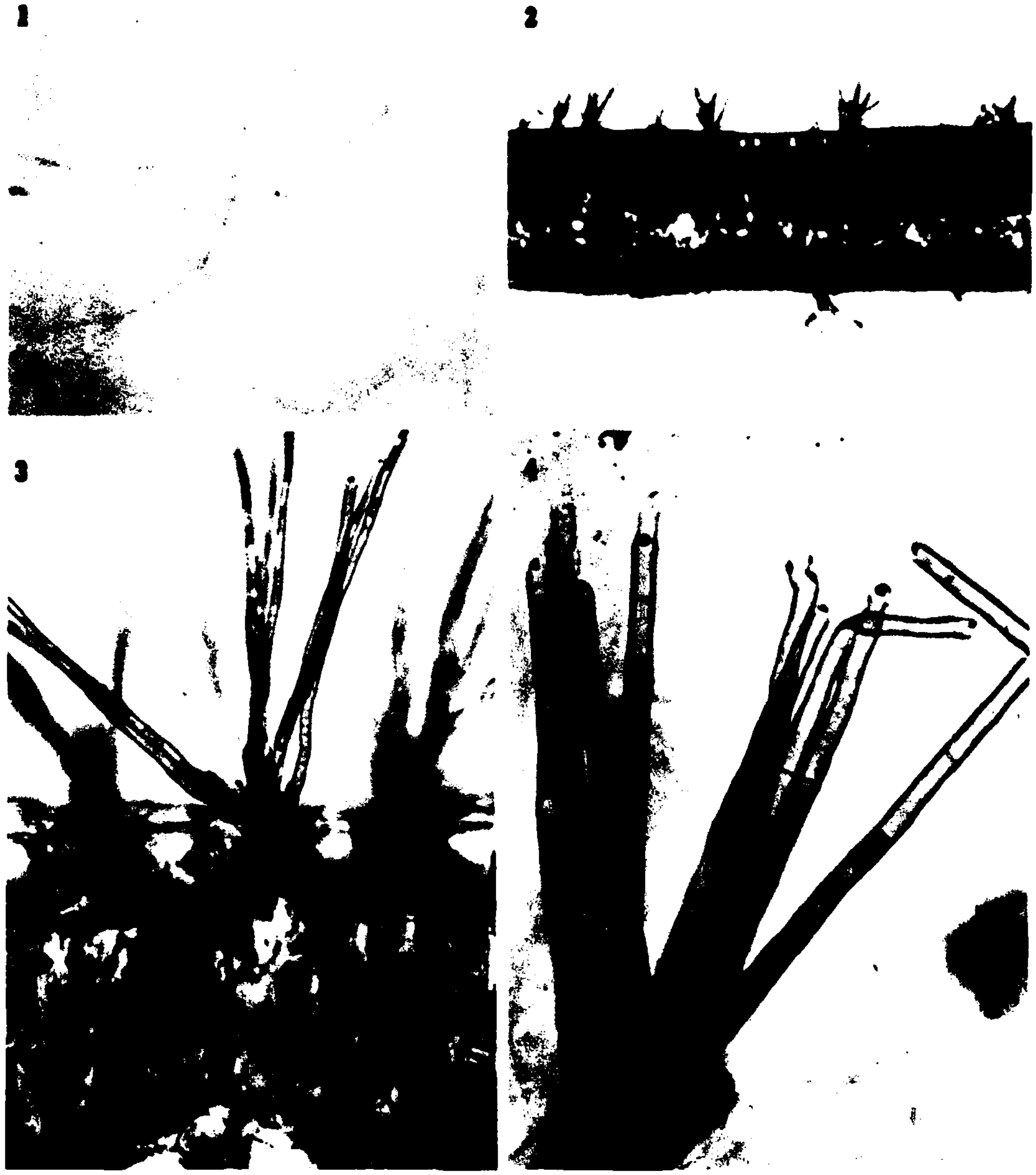

Figure 1. Microscopic (light) details of *Cercospora rodmanii* morphology and pathological histology. 1. Mycelial infection through stomatal opening (25 μ) 400X. 2. Conidiophores on leaf. Note amphigenous fruiting on leaf (350 μ thick) 40X. 3. Condiophores, 200X. 4. Conidiophores, 400X.

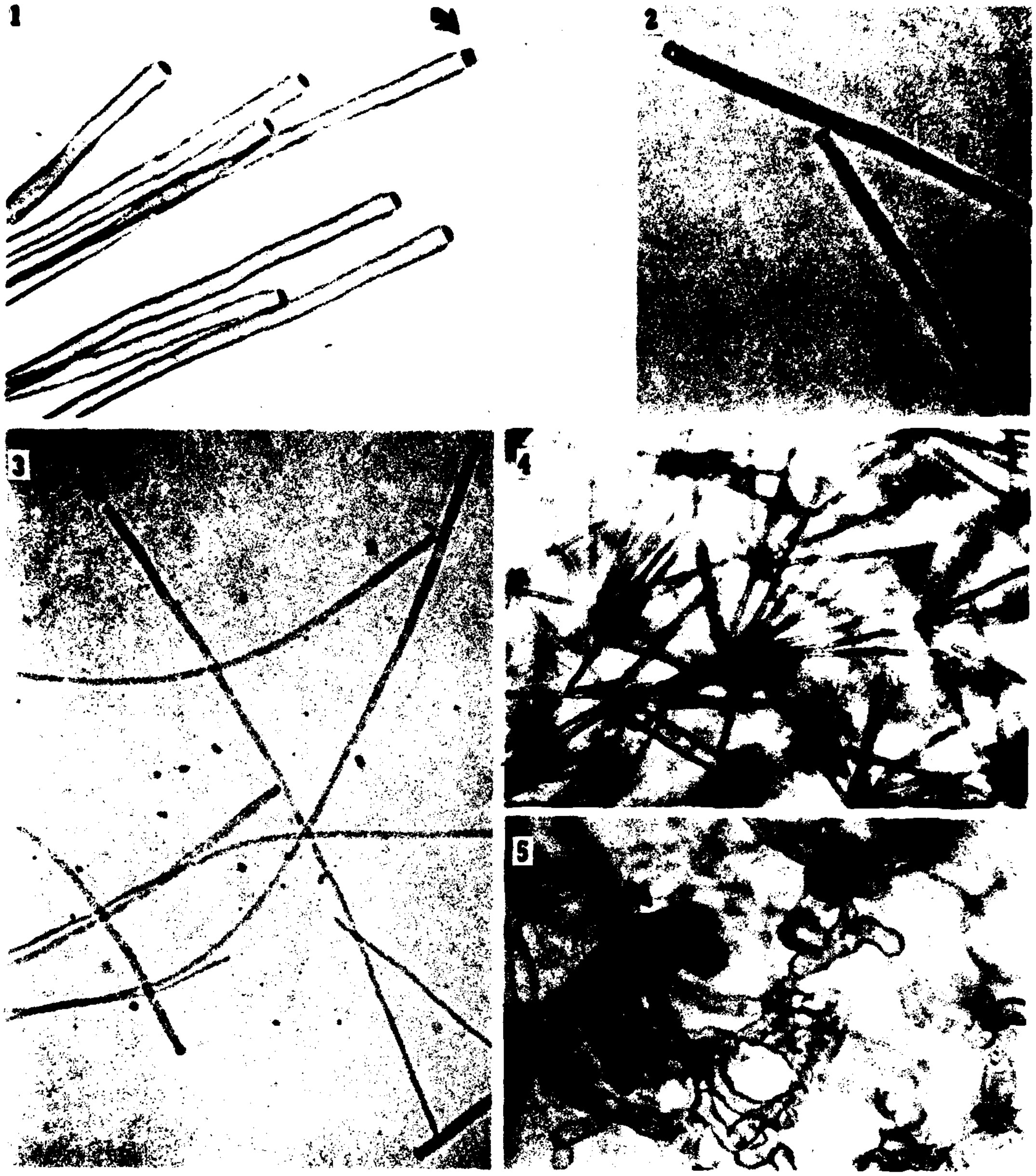

Figure 2. Microscopic (light) details of *Cercospora rodmanii* morphology and pathological histology. 1. Conidiophores (5 μ wide) showing conidium attachment (arrow) 400X. 2. Conidium showing truncate base, 400X. 3. Conidia of *Cercospora rodmanii;* arrow points to 300-μ-long conidium. 4. Top view of fascicles of conidiophores on leaf surface, 200X. 5. Subepidermal mycelium; arrow points to base of conidiophores, 400X.

Fusarium roseum 'Culmorum'

In 1974, a disease of *Stratiotes aloides* L. (Hydrocharitaceae) was discovered near Wageningen, The Netherlands. Mature plants had symptoms of root and crown rots and severely diseased plants appeared to sink gradually as a consequence of tissue decay. A few infected plant parts were taken to Gainesville, where a group of fungi was cultured from them, including predominatly a *Fusarium roseum* 'Culmorum' (Lk. ex Fr.) Synd. & Hans. In view of the close taxonomic relationship between *S. aloides* and *Hydrilla verticillata*, the pathogenic potential of these fungi to the latter was of obvious interest. Among the fungal isolates obtained from *S. aloides*, only 'Culmorum' was capable of killing hydrilla.

The effects of the 'Culmorum' isolate on hydrilla were determined in three test systems. The first one consisted of incubating 8- to 10-cm-long terminal portions of hydrilla shoots in 3- by 15-cm glass tubes with 40 ml of sterile water to which was added dense macroconidial suspensions. A dose and effect relationship was seen on inoculated hydrilla; at lower inoculum levels the shoots were only partially damaged or killed, while at higher inoculum levels the effects were drastic or lethal.

In the second system, 20-ℓ aquarium tanks were layered with river sand, filled with 14 ℓ of water, and planted with 100 terminal ends of hydrilla shoots, each with an active growing bud. After 2 days, the tanks were inoculated with conidial suspensions of 'Culmorum' at approximately 80,000 or 90,000 conidia per millilitre of water in tanks. Three weeks after inoculation, hydrilla shoots started to discolor and developed signs of rotting. In about 5 weeks, the shoots broke down completely, and some that were still green were defoliated and uprooted and floated to the water surface.

In the third system, the fungus was grown for 2 weeks on a sterilized mixture of nine parts sand, one part oatmeal, and three parts water, and mixed with the bottom sand in hydrilla tubes at 1:1 and 1:10 proportions (w/w) of inoculum and sand. Controls had sand-oat-water mixture without the fungus, mixed with an equal weight of sand. A hydrilla plant with shoots, roots, and at least one tuber was planted per inoculated and control tubes. After a week, the inoculated plants turned pale and were dead by the end of 14 days.

In all these systems, the inoculated fungus could be reisolated from inoculated, dead, dying, or green hydrilla shoots after surface sterilization and planting on potato dextrose agar. Controls did not yield the fungus. In addidion, the conidia were observed to germinate on, and penetrate into, hydrilla tissue, which confirmed the pathogenic capability of the fungus.

In order to decide that the effects of the 'Culmorum' isolate on hydrilla were specifically due to its infectivity and not due merely to massive numbers of fungal spores in water, a comparative inoculation

test was set up. In this test, three unidentified *Fusarium* spp., isolated from hydrilla in Florida, a *F. roseum* from *Ficus elastica* Roxb., a *F. roseum* 'Graminearum' from *Eichhornia crassipes* (Mart.) Solms in Florida, and two isolates of *F. roseum* 'Culmorum' from the State of Washington were included. The test tube procedure described first was used, with inoculum densities between 2,500 and 250,000 conidia per millilitre of treated water. The results confirmed that the Dutch 'Culmorum' was indeed unique in its effects on hydrilla. The three *Fusarium* spp. from hydrilla and the *Ficus* isolate of *F. roseum* did not damage hydrilla even at higher levels of inoculum. The 'Graminearum' from *E. crassipes* and the Washington 'Culmorums' were capable of damaging hydrilla, inciting similar symptoms as the Dutch 'Culmorum.' However, the threshold of inoculum needed to cause damage by these isolates was approximately 60,000 conidia per millilitre, or 2.4 times higher than that of the Dutch 'Culmorum.' The Dutch isolate hence was not only pathogenic to hydrilla but also was more virulent than any *Fusarium* tested.

Since the Dutch isolate is still maintained under quarantine due to its foreign origin, the effects of the local 'Graminearum' isolate were tested in an outdoor, large-scale pool test. Hydrilla in plastic swimming pools were inoculated with mycelial homogenates. One pool was inoculated with a suspension of approximately 0.18 g/ℓ conidia and mycelium and a second pool at 1 g/ℓ. Control pools were maintained. There were isolated patches of dead hydrilla a month following inoculation, but no appreciable control of this plant was achieved in pools. This lack of field efficacy may be due to insufficient levels of inoculum used or poor virulence of 'Graminearum' or both.

Host range of the Dutch 'Culmorum' to a few common aquatic plants of Florida has been tested. Rooted aquatic plants in 5- to 200-ℓ glass containers were screened, using inoculum of 125,000 conidia per millilitre. At this level, the isolate was lethal to *Ceratophyllum demersum* L. (Ceratophyllaceae); *Egeria densa* Planchon and *Vallisneria americana* Michx. (both of Hydrocharitaceae), and *Najas quadalupensis* (Spreng.) magnus (Najadaceae). On *E. crassipes*, it caused severe root rot. *Alternanthera philoxeroides* (Mart.) Griseb. (Amaranthaceae); Nuphar luteum (L.) Sibthrop, & Smith (Nymphaeaceae); and *Ruppia maritima* L. (Ruppiaceae) were not affected by this isolate.

Host range tests on terrestrial crops and nontarget plants have been underway. Two types of tests have been undertaken--one on infestivity of seeds and the other on infestivity of foliage, stems, and roots.

In the first test, 68 crop plants have been screened for their ability to withstand seed infection by the Dutch isolate. *Fusaruum roseum* 'Culmorum' isolates can be seed pathogens and may colonize and rot preemergent seeds. Our test was, therefore, aimed at determining this potential with the Dutch isolate. Conceivably, this isolate could pose problems if water treated with the fungus is used for crop irrigation, assuming, for now, the fungus would survive in

water for long periods of time and at large enough inoculum levels (which is unlikely). The test was conducted by growing plants from fungicide-free seeds in soil infested with 38,000 conidia/g soil. Seed were allowed to germinate and establish seedlings and were observed for 3 weeks or more. The percentage of reduction in seed germination over controls and symptoms or root or collar rots on seedlings was assessed. Any partially germinated seeds and seedlings with symptoms or rots were assayed for the Dutch 'Culmorum.'

Of the 68 cultivars belonging to 43 species in 14 families tested, 33 were not affected by the fungus, while 35 others registered reduction in germination. These reductions, expressed as percent reduction from the controls, ranged from 40 to 100, the latter in the case of castor bean, Hadden wheat, and Thorogreen lima bean. However, of the 35 varieties with reduced seed germination, only 13 had symptoms of collar rot, brown lesions at the hypocotyls or cotyledonary rot associated with the inability of the cotyledons to shed seed coats after germination.

The 'Culmorum' was reisolated from only 5 of the 13 cultivars that had symptoms. It appears that at very high inoculum levels, such as used in this test (35,000 spores/g of soil), some reduction in germination may result in some crops, together with diseaselike symptoms. However, these results do not negate the biocontrol potential of this pathogen for the following reasons:

- a. It is unlikely that crops will be irrigated with the pathogen-treated water when inoculum levels are high.
- b. The fungus may not survive or multiply to the inoculum levels used in this test.
- c. The fungus is not likely to survive in the warm soils of Florida.

Furthermore, these results are to be evaluated in relation to post-emergence and field host-range tests.

In the second test, seedlings of 44 cultivars were tested for foliar, stem, and root infections by the Dutch isolate. Seedlings were established in sterilized soil in pots and sprayed with conidial inoculum of approximately 1 million spores per millilitre of water. The fungus was sprayed on leaves and stem until the excess ran off into the soil around the stem. Plants were then incubated in the greenhouse for 3 or more weeks and observed for infections on leaves, stems, and roots. In all cases, the fungus failed to infect. Additional hosts are being tested at this time.

The temperature optimum for in vitro growth of the Dutch isolate has been determined. On potato dextrose agar, the fungus grew between 15° and 30°C, but the rate of growth was better between 16° and 27°C, and the peak growth was attained earliest at 21°C. The fungus thus appears to be adapted for relative cooler temperature, and is likely to survive in Florida water but not in the warm soils of the southeastern United States.

BIOLOGICAL CONTROL TECHNOLOGY DEVELOPMENT

Biological Control of Aquatic Weeds in Puerto Rico

by

Leonce Bonnefil*

Introduction

An aquatic plant control program in Puerto Rico may not be successful if the peculiar nature of the weed infestation on the Island is not first understood. If the program is based on the area occupied by the pest plants, the importance of the infestation problem will be grossly underestimated; and if corrective measures are extrapolated from other countries, they may well prove inefficient or exhorbitant.

Annual cycle of abundance of the aquatic weeds

Puerto Rico is a roughly rectangular island 160 km long and 56 km wide. A mountain range spans it east-west with elevations up to 1334 m. Rainfall is abundant, reaching in places 190 mm a year. The north coast is cut by several permanent streams that are all dammed, sometimes twice, for the production of electrical power.

The obnoxious aquatic plants develop along the sinuous course of the streams and within the innumerable fingerlike coves of the reservoirs. Twice a year the weed masses are washed downstream and first accumulate at the reservoirs in May, later at the estuaries in October, until they are flushed out at sea where they die in contact with saltwater.

The temporary accumulations at the dams and at the river mouths are a nuisance and may be considered a threat to the safety of riverbank communities in addition to interfering with public health, commerical and sport fisheries, recreation, etc. Their removal, whatever the method used, is a costly undertaking and the benefits to be gained must be carefully weighed against the financial outlay.

The aim of the present program is to keep the weeds from proliferating in the headwaters and along the streambanks, thus cutting down on the number of plants that can float downstream in the rainy season causing inconvenient or hazardous accumulations.

Soon after the floating masses accumulate, bank species grow over them forming mats firmly anchored to the sides of the streams, reservoirs, or lakes. These mats are a much more serious menace than the floating

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* Department of Natural Resources, San Juan, Puerto Rico.

plants; they will resist the most violent current, reduce the flow of rivers and choke good-sized streams, impede navigation, interfere with the movement of fish and shrimp, and alter water quality creating a condition of near stagnation.

Destruction of these anchored weed mats in the upper parts of the streams and along their course is difficult by conventional methods and sometimes even impossible due to Puerto Rico's rugged topography that excludes the movement and operation of harvesting machines or spray equipment. It would seem then that biological control would be a favorable alternative.

Commonwealth Agencies responsible for weed control

Aquatic plant data in Puerto Rico are the product of surveys and observations conducted by the Area of Scientific Research of the Department of Natural Resources of Puerto Rico. By ordinance of the Governor's Office in April 1975, the Department of Natural Resources (DNR) was formally charged with the coordination of all efforts in weed management in Puerto Rico. In August of the same year, representatives of all local agencies involved in water resources management decided the DNR was the agency best manned to conduct research in weed control. Currently, it is expected that to that research responsibility will be added an operational phase when a contract will be passed between the Corps of Engineers and the DNR admitting Puerto Rico into the Aquatic Plant Control Program under the River and Harbor Act of 1958 amended in 1965.

Aquatic plant species and their relative abundance

The aquatic plant species of major occurrence in Puerto Rico are waterhyacinth (*Eichhornia crassipes*), alligatorweed (*Alternanthera philoxeroides* (Mart.)), paragrass (*Panicum purpurascens*), and coontail (*Ceratophyllum demersum*). Isolated stands of Illinois pondweed (*Potamogeton illinoensis*), waterlettuce (*Pistia stratiotes*), bulrush (*Scirpus validus*), cattail (*Typha dominicensis*), and smartweed (*Polygonum portoricensis*) occasionally can be found.

As indicated earlier, waterhyacinth assumes particular importance when it becomes overgrown with alligatorweed, paragrass, smartweed, and sometimes terrestrial species like sugarcane, castor bean, and others. The floating mat sometimes is several acres, sturdy enough for people to walk over. It is then very difficult to break up mechanically and represents a difficult and costly problem.

Specific controls for the aquatic plants

Waterhyacinth and alligatorweed, the two more significant weed species, are attacked in Puerto Rico by several native insect and mite species, but none of them of great significance. These organisms may have low biotic potentials or be subjected to highly efficient natural enemies.

In other countries, the plants are known to be significantly stressed by insects of adequate population levels. Paragrass may be controlled by chemicals or by mechanical cutting along the banks. If a continued chemical or mechanical and biological control is put into action at the time of lowest annual weed infestation (October-November), significant results may be achieved with minimum effort; from then on, simple maintenance practices would keep the week populations at acceptable levels.

In the areas where the bank is steep and there is no boat ramp in the immediate vicinity, biocontrol may be the only possible method, the others being difficult or impossible. Should it become necessary to clear reservoirs or estuaries of large weed accumulations, then the problem would be one of great cost involving harvesting machines, loaders, dump trucks, and large disposal areas. In 1972 (when costs were still fairly low), Lake Cidra, a 245-acre lake that is 20 percent hyacinth covered, was cleared in this manner at a cost of around $130,000. The plants were back less than a year later.

Biological control efforts to date

The DNR has established facilities quite satisfactory for the study of the waterhyacinth weevil (*Neochetina eichhorniae*). An initial experiment in a glass greenhouse clearly showed the adverse effects of high temperatures and chlorinated water source. After the initial experiment, a screened shed and a supply of untreated underground water were secured on the grounds of the University of Puerto Rico where a captive population of the weevils is currently maintained and is reproducing quite satisfactorily.

Preliminary host specificity tests have been completed and the final results are being presented to the Puerto Rico Department of Agriculture, which is responsible for the introduction of plants and animals.

As soon as the official permit of introduction is obtained, populations of the insect will be released at selected sites in Puerto Rico away from agricultural areas. These populations will be monitored to ensure that they will have become successfully established; their efficiency as control agents will also be measured. It is not anticipated that this insect alone will bring the hyacinth down to a satisfactory level. Experience from foreign countries, namely the United States, points to the benefit of a combined action of the weevil and other biological control agents; the moth *Sameodes albiguttalis* seems to be particularly promising.

The flea beetle, *Agasicles hydrophila*, now recognized as a biocontrol agent of indisputable efficiency for alligatorweed, should also be considered for introduction. Alligatorweed is closely associated with waterhyacinth and would fill the niche left by waterhyacinth. The alligatorweed would then cover the floating mass of decaying organic matter tightly held together by paragrass and other creeping bank vegetation.

Areas to be covered by the program

There is no reason to believe that the program could not involve--

at least eventually--all the artificial lakes managed by the Electrical Power and the Water Resources Authorities on the north and west coasts, such as Lakes Loiza, La Plata, Dos Bocas, Comerio, Cidra, Guajataca, and Toa Vaca. These sites would be widely separated by topographical obstacles and the introduced populations would be physically isolated. Whether or not that isolation would have negative effects will have to be discovered.

In addition to these main streams, many tributaries of varying sizes are completely overgrown by tightly interwoven weeds generally imported by waterhyacinth. These creeks or brooks no longer have water flow; there is no exchange of gases with air; oxygen is depleted to near anoxia; and the aquatic fauna is nonexistent. These water courses are located at the bottom of crevasses making it impossible to transport mechanical weed removal devices or spray rigs to them. Biological control is the only answer to the rehabilitation of these tributaries that will also prevent the problem of unusually strong rains flushing the weeds out into lakes and rivers starting or reinforcing weed infestation.

Plan of Work

The activities discussed below are scheduled for the first 3 years of the research program.

During the first year of the research program, it is planned to release the waterhyacinth weevil *Neochetina*, which has been studied so far as a captive population in Puerto Rico. The sites will be closely monitored to ensure that the populations have successfully established themselves. The efficiency of the insect for biological control will also be assessed. Concurrently, authorization will be sought to introduce jointly or separately the moth *Sameodes albiguttalis* and the alligatorweed flea beetle *Agasicles hydrophila*. Captive populations of these two insects will be developed in the greenhouse, and their bionomics will be studied.

In the second year, it is expected that the preliminary testing of *Sameodes* and *Agasicles* will have been well under way. Authorization will then be asked to release *Sameodes*, alone or together with *Agasicles*. Field release will be made separately and in combination with the weevil *Neochetina*, which by that time should be well established.

In the third year, it is anticipated that sufficient evidence would have been produced so that the moth as well as the flea beetle would be authorized for liberation. By that time, a variety of field populations should be under observation and a wealth of new information should come out of that phase of the research program.

It must be mentioned at this point that normal delays are anticipated in the processing of official permits. Therefore, the program described above is subject to changes in the projected schedule.

MECHANICAL CONTROL TECHNOLOGY DEVELOPMENT

An Overview

by

H. W. West*

As part of the Corps of Engineers (CE) Aquatic Plant Control Research Program (APCRP), the U. S. Army Engineer Waterways Experiment Station (WES) is conducting research on the use of mechanical systems alone or to augment other methods to manage problem aquatic plants in water bodies of interest to the CE. The overall goal is to develop equipment and techniques that can be used to mechanically control various types of aquatic plants in a wide range of environmental conditions.

Technical Areas

The research has the following four main technical areas:

a. Quantitative description of the CE operational environments.

b. Determination of the operational performance of existing equipment systems and subsystems.

c. Development of analytical models for use in the design and evaluation of mechanical control equipment.

d. Design and development of new equipment to improve the state of the art of mechanical control technology.

Work to be conducted under each of the four technical areas will be described in a long-range research plan that is currently being developed by WES and should be completed early in the second quarter of this fiscal year.

Quantitative description

The first technical area is the quantitative description of the CE operational environment. Many of the CE's lakes and rivers have stumps, trees, and other floating and submerged debris that pose problems to the successful operation of many types of mechanical equipment. Other physical features, such as shallow bottoms and varying bank topographic and vegetation characteristics, are equally important to the cutting, removal, processing, and disposal of aquatic plant material. Floating

* U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

aquatic plants and floating islands of aquatic plants and soil material pose an even greater challenge to the mechanical equipment design problem. Emergent aquatic plant species probably will require a completely different equipment design than that required for most other aquatic plant species. Therefore, if mechanical equipment is to be designed to be effective as a control method, the quantitative description part of the research will provide the basic data needed for successful design and operation of the equipment and/or machines.

Preliminary work on defining a portion of the operational environment for mechanical control technology development has been accomplished by WES for the Jacksonville District. This work consisted of an evaluation of a 400-mile reach of the Saint Johns River in terms of physical characteristics of the river where infestations of waterhyacinths occurred. In this study, water depths and areas of plant coverage of waterhyacinths on the river were defined. It was found that more than 50 percent of the areas containing plants occur in water depths less than 2 ft, thereby indicating that the presently available waterborne aquatic plant control machines would most likely experience significant problems operating in these river conditions. Additional work of this nature is needed to better define the physical characteristics of the CE operational environment.

Operational performance

The second technical area of research is the determination of the operational performances of existing mechanical control systems and the long-term effectiveness of those systems, in terms of limiting regrowth of the plants. Currently, there are several manufacturers who sell different pieces of equipment that provide, to some degree, the capability for cutting, removing, processing, transporting, and/or disposing of aquatic plant material. In the operational performance part of the mechanical research program, several of these pieces of equipment will be evaluated to determine their field performance and their limitations and deficiencies in providing mechanical control of aquatic plants. Large-scale experimental tests also will be conducted on those systems that have been determined to have the best overall potential for mechanical control. These tests will also be designed to provide "a measure of effectiveness" of the equipment in terms of limiting the regrowth of the aquatic plants.

Another part of this research will determine the frequency and time period needed to provide the most effective mechanical control operations for the various types of aquatic plants. The results of this research might indicate that the most effective mechanical control operations would be obtained by conducting the operations in the winter months when the plant growth and biomass is minimal, followed by a second (and possibly third) control operation at specific times during the plants' main growth period. The research also should definitely indicate those times during the plant growing cycle that are best in terms of overall mechanical control operations. For example, lawn-cutting operations are more easily performed when the lawn grasses are

less than 5 cm tall. If one waits until the grasses are 15 cm tall or greater, most small grass-cutting machines are very ineffective, and one, therefore, has to resort to other methods and equipment for grass control.

Analytical models

The third technical area is the development of analytical models that can be used in the design and evaluation of the mechanical control equipment. Since mechanical equipment will surely continue to be used as a primary control method for aquatic plants in the future, this will require that the CE's operations have minimal impact on the environment. As a result, several machines have been developed by various manufacturers (Figure 1) and many of them have been deployed in a variety of water body conditions. In some water bodies, the machines have worked adequately; in others, they have not performed as well as expected. Experimental tests also have uncovered inconsistencies in the performance of some of the machines. These inadequacies in the present group of aquatic plant control machines (APCM) demonstrate that many were designed without proper knowledge of the effects of the environment on APCM operation. Rational and successful testing and deployment of APCM's require a quantitative understanding of the operational environment, coupled with an equal understanding of:

a. How the APCM cut or detach the plant material from the attaching medium, such as a substrate, or other floating material.

b. How the detached plant material is transferred to a waterborne platform.

c. How the material is processed for reduction of volume or biomass.

d. How it is transported over water and/or land.

e. How it is disposed.

- LIMNOS SYSTEM
- LANTANA COOKIE CUTTER
- ARUNDO SYSTEM
- AZTEC WATER WEEDER
- ALTOSAR SYSTEM
- AQUAMARINE AQUA-TRIO SYSTEM
- ALLIED AQUATICS SYSTEM

Figure 1. Presently available aquatic plant control machines

Once these operational steps are clearly understood, improved equipment designs can be produced and a more effective control operation for aquatic plants can be conducted.

Research to date has resulted in the development of two analytical models (the Winfrey and Limnos models) that have potential for use in an overall procedure for predicting APCM performance. These two models, however, do not make up a general comprehensive APCM performance prediction capability. Such a capability would have to account for all of the functional steps as stated above.

During FY 80, WES plans to formulate a basic model (Figure 2) that will allow prediction of APCM performance in various water bodies and under various aquatic plant characteristics. The anticipated output from the model will be the equipment performance rates for each operational function, such as cutting, transporting, processing, and disposing of aquatic plant material. A cost subroutine is to be included also so that the economics of a given APCM can be compared to other control measures, such as chemical and biological.

Design and development

The fourth technical area is the design and development of new APCM's to improve the state of the art of mechanical control. Work in this area will be somewhat limited until some of the other basic work has reached significant milestones. This work will most likely be limited to the design of component parts of each functional area, such as the design of new plant material processing equipment. New subsystem designs should benefit significantly from the other three basic research thrust areas. Once a new design for a component part of a subsystem or machine is produced, that design will be evaluated, using the APCM model in terms of overall subsystem and/or total system performance. The new design(s) can also be evaluated in terms of the plant and water body characteristics to determine how well the design concept is capable of performing its function in the different operating conditions.

Conclusions

We are definitely moving forward in our basic and applied research to develop a better understanding of mechanical control technology and to determine cost-effective equipment and improved operational techniques for mechanical control of aquatic plants.

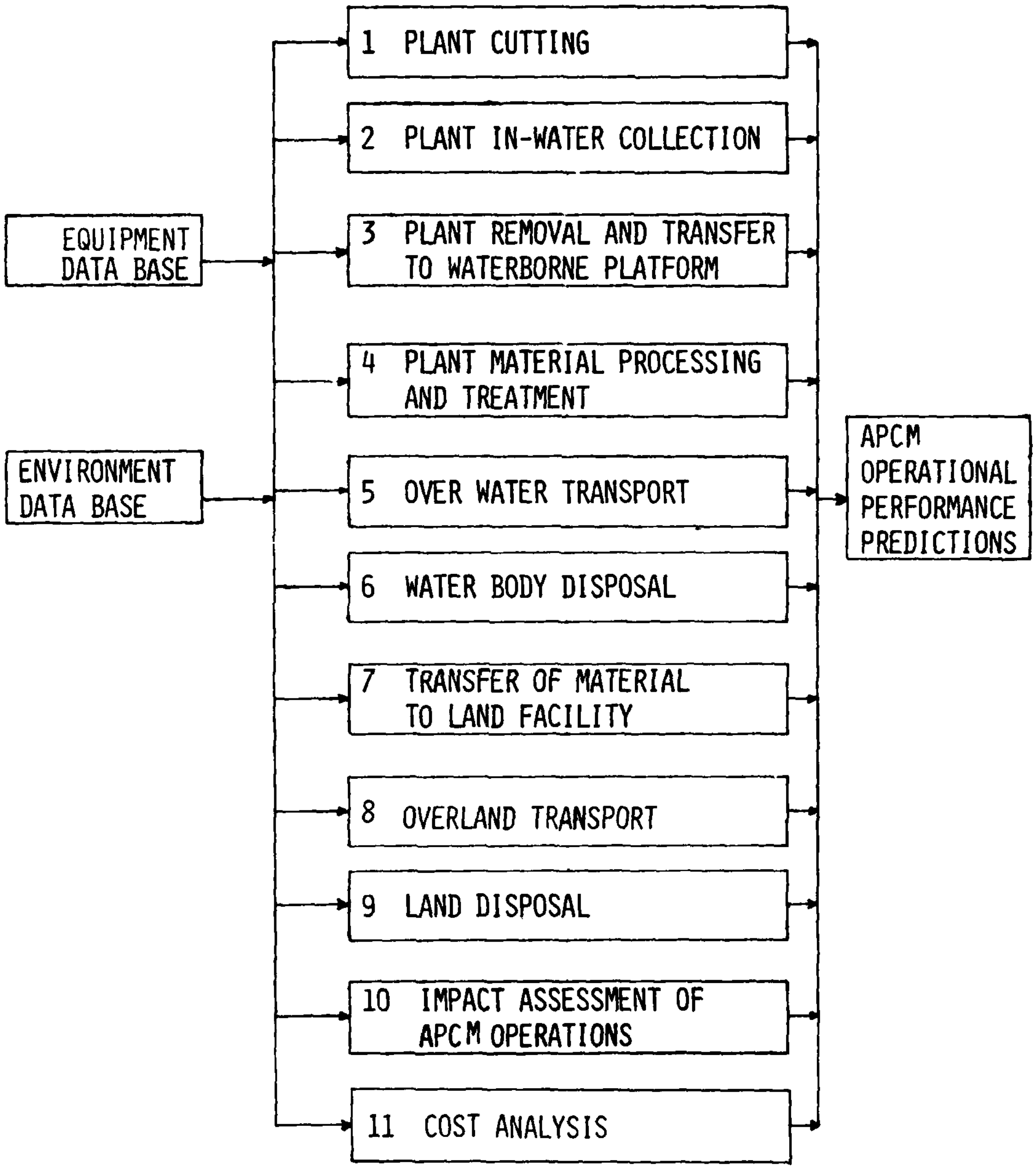


Figure 2. Conceptual APCM model

MECHANICAL CONTROL TECHNOLOGY DEVELOPMENT

A Computer Model and Systems Cost Analysis of the Limnos Aquatic Plant Harvesting System

by

John H. Neil*

Introduction

The mechanical control of aquatic plants has been limited by the availability of productive cost-efficient harvesting systems. Likewise, where mechanical controls have been implemented, harvesting costs have been poorly documented with respect to the effect of environmental variables such as density of plant growth, means of disposal and size of areas out, and variable economic inputs, including depreciation of equipment, wages, fuel, repairs, and downtime. This has resulted in reported costs ranging from \$80 to \$800 per acre. The combination of low productivity and uncertain costs has limited the practical application of harvesting as a safe and beneficial control procedure.

In a program designed to improve the technology of mechanical control and to rationalize costs, the U. S. Army Corps of Engineers evaluated available harvesting equipment. As a follow-up, a "Request for Quotations" was issued 13 January 1978 for the "Design, Manufacture, Test, and Delivery of One or Two Mechanical Weed Control Systems," the purpose of which was to elicit innovation in improved harvester designs from the private sector. Evaluation factors included overall design concept, level of energy input, level of operational control, estimated per ton operational cost, estimated cost of system, and target date of initiating field demonstration. The Limnos Aquatic Plant Harvesting System was selected, and on 3 February 1979 an order was issued to Limnos Limited.

The contract as negotiated related specifically to the control of hydrilla (*Hydrilla verticillata* Royle) as specified in Environment 2 of the Request, although it was intended that the harvesting capability would also be evaluated for waterhyacinth (*Eichhornia crassipes* Mart.).

Prior to the Corps' request, a prototype, two-stage harvester had been constructed and evaluated by Limnos Limited. The original design specifications called for a 2-acre and 15-ton-per-hour capability in rooted submersed aquatic macrophytes. Field testing demonstrated the principles to be valid, and production met the objectives established

* Limnos, Ltd., Toronto, Canada.

in Eurasian watermilfoil (*M. spicatum*) and other species typical of temperate climates.

The Request for Quotations by the Corps had an objective of 30 tons per hour in hydrilla; the mechanical design was modified to incorporate features required to increase productivity.

Construction commenced in February 1979 and was completed in June 1979. The four units were launched in Canadian waters and tested; minor modifications and adjustments were made. In early July, the units were prepared for shipment and delivery was made on three tractor trailer units to Wildwood, Florida, during the week of 16 July 1979.

The contract specified a 30-working day demonstration of the equipment by the contractor. This was completed 31 August. During the demonstration period, records of operation and production were kept by a Corps project supervisor and the Limnos staff. The final responsibility of the contract was the preparation of a report on the system based on a computer model using data collected from field operations. The report has been prepared to fulfill the requirement.

Concept of Design

Available mechanical harvesting systems have been based on a single-stage operation in which plants are cut and removed by a harvester which contains the unmodified plant material on the harvesting vessel. When loaded, the plants are carried ashore and off-loaded or transferred to a transport barge.

The Limnos Harvesting System utilizes a two-stage system in which plants are cut by an independent cutter and allowed to rise to the surface. The harvester following the cutter gathers the plants from the surface, grinds them to a slurry, and drops the fluidized product into the hold of an attached barge. When loaded, the barge is released, an empty one "plugged in," and harvesting continued. The loaded barge proceeds to shore where it is off-loaded by means of a self-contained slurry pump (Figure 1).

Operation of a contract harvester over several seasons using two types of single-pass harvesters provided a background of experience which identified the limitations of these systems and suggested possible solutions. The following paragraphs describe the major limitations identified and the solutions implemented. These include:

- a. Forward speed.
- b. Depth and width of cut.
- c. Materials handling.
- d. Load capacity.

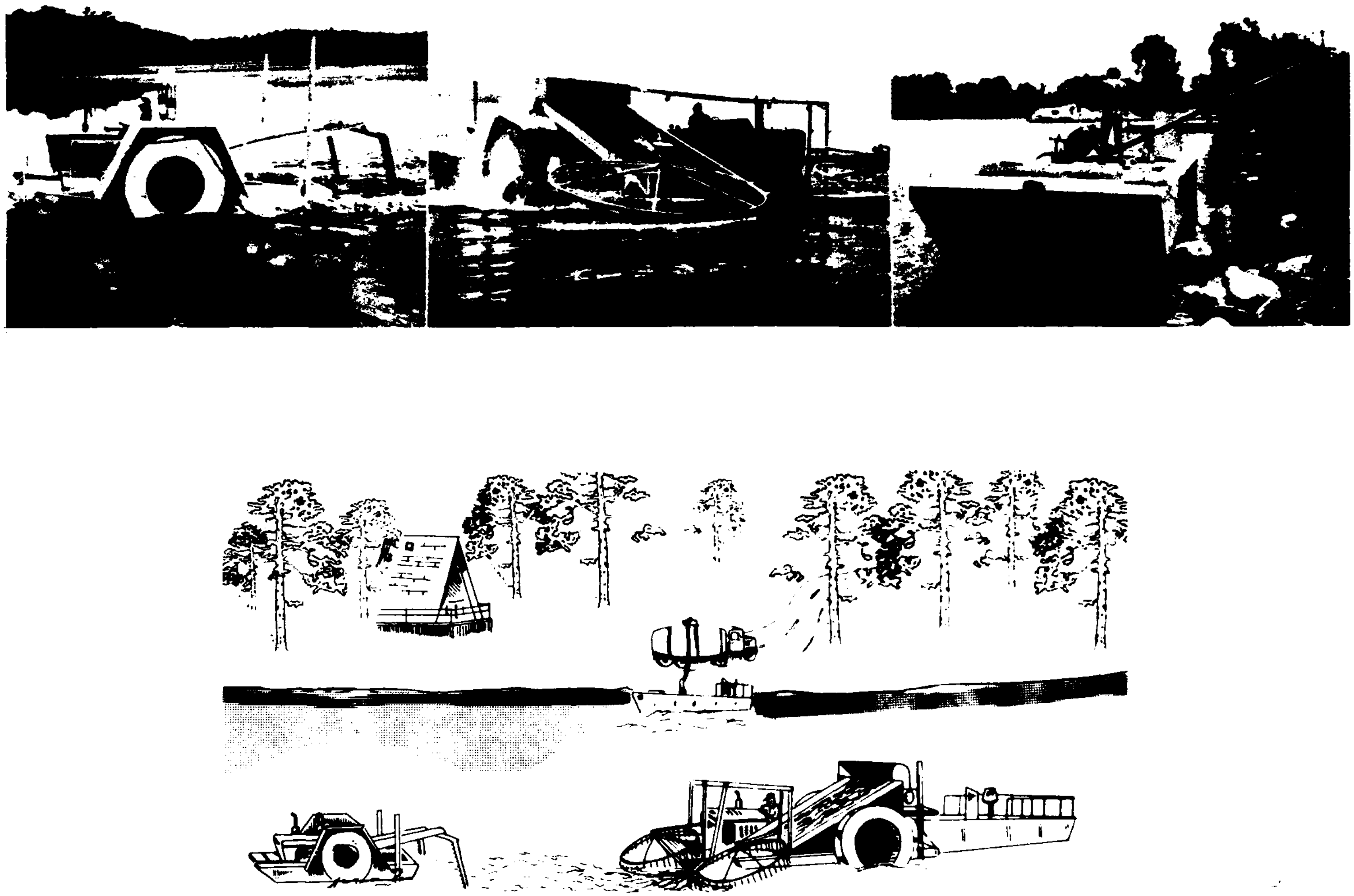


Figure 1. Limnos Harvesting System

e. Downtime.

f. New capabilities.

Forward speed

Single-pass systems are limited in their forward speed to about 2 mph by a conveyer submerged to the depth of cut. At higher speeds, a cone flow is created in advance by the conveyer causing the plants to go down or around the harvester head. By separating the cutting and pickup operation and "force feeding" the conveyer with the collector wheels, it was possible to increase the forward speed.

Depth and width of cut

Conventional harvesters use a cutting and elevating system of equal width requiring an increasingly large elevator and front-end loaders as the depth and/or width of cut is increased. The two-stage system enables plants to be cut to a depth of 8 ft and width of 16 ft. When plants float to the surface and are gathered by collector wheels, an elevating conveyer of practical size can be used.

Materials handling

The average bulk density of the harvested submersed aquatic plants at the demonstration was about 18 pcf. In a system having an objective of 30 tons/hr, about 3500 cu ft/hr of plant material would be produced. The Limnos approach to handling this large bulk density is to process the plant material to a condition which could be pumped. As plants are processed through the grinder, a slurry with a bulk density of 62 pcf and 5 percent solids is produced.

One of the major constraints in off-loading unprocessed plants is locating suitable landing sites close to the harvesting operation where the conveyer can link the barge and a large truck. In built-up or swampy shoreline areas, long water hauls are frequently required. By off-loading the slurry through a pipe, a clean operation can be maintained close to the harvesting site since the barge can be positioned safely offshore and the slurry can be pumped to a truck located on a roadway or suitable solid ground.

Load capacity

The use of an attached but independent barge during the harvesting function allows for much larger loads (up to 15 tons) to be carried to shore. Also, during loading of the barge, the harvester remains very stable with good maneuverability. The harvester is not required to transport plant loads to shore, thereby allowing continuous harvesting.

Downtime

Two principal sources of downtime with existing cutting systems were found to be damage to front-mounted cutter bars and mechanical failures of power and hydraulic components. The use of a hinged, rear-mounted cutter allows the assembly to swing freely over bottom obstructions and has virtually eliminated damage to the knife. The balance

of the power and mechanical systems for the Limnos Cutter Unit has been drawn from agricultural machinery of proven dependability. Diesel tractors are used to provide axle, hydraulic, and power-takeoff (PTO) power, and liquid manure pumps are used to pump the slurry into trucks or onto acceptable disposal sites.

New capabilities

Units of the harvesting system can be used independently or in combination to provide a flexibility of operation suited to the particular problem and the local environment. The cutter may be used alone where remote conditions or low biomass will not result in a nuisance from floating plants. The cutter and harvester can be used together to cut, collect, grind, and return the ground-up plants to the water. Virtually all of the processed plant material sinks within a few feet of the harvester leaving only a few small (1 in. or less) stem pieces floating. In this mode of operation, two operators can work continuously in locations remote from a landing site to provide boat channels through open water areas.

The product of the grinding process makes a slurry suitable for subsequent uses for methane generation, animal feeds, or the direct application to land as a green manure.

Demonstration Location and Test Procedures

Harvesting operations were conducted on the Withlacoochee River, which is located about 60 miles west and north of Orlando, Florida. It is a brown water river, 50-ft wide in narrow areas opening to a series of small lakes of several hundred acres. Harvesting operations were carried out over about 10 miles of the waterway.

The principle objectives of the testing program were to gather data and develop operating experience for a new system in a new environment. It was also anticipated that some modification and adjustments to the equipment would be made as the need was demonstrated.

Individual test programs included an evaluation of the capacity of the cutter alone; tests involving the operation of the cutter and harvester working together in a cut, grind, and return operation; and an evaluation of the complete harvesting system including barging to shore to a disposal site. The majority of the comprehensive testing of the total system was conducted in Bonnet Lake where no convenient vehicle access sites were available and plant slurry was disposed of by pumping it 60 ft inland onto islands located near the harvesting sites. During the demonstration period, various control procedures were applied to a total of 136 acres of which full harvesting accounted for 70 acres; cut, grind, and return 8 acres; and cutting alone 58 acres.

While the system was designed for the control of hydrilla, some testing was also conducted on its ability to harvest waterhyacinth.

Where incidental patches of plants were harvested in hydrilla operations, no problems were encountered. As the density increased, difficulty was found in feeding the bulky disorganized hyacinth plant material through the throat of the grinder. Once it entered, however, it was immediately reduced to a slurry similar in appearance and consistency to hydrilla and the product was readily handled by the barge slurry pump. When returned to the water, the fragmented material sank and disappeared almost immediately. The collector wheels were found to gather and feed low density small plants efficiently. Because of the large biomass present in dense stands of waterhyacinths, smaller and stronger collector wheels would be necessary to feed smaller quantities to the conveyer and prevent overloading of the grinder. A means of regulating the plant flow so that the grinder is presented with a compacted organized feed, would enable the harvester to process waterhyacinths in a more efficient manner.

In the course of the demonstration, suitable operating practices were developed and modifications in design were identified that would add significantly to harvesting productivity. The four-piece Limnos system was operated over a period of several days and the average harvesting rate was 22 tons/hr (or 1.2 acres/hr) in very dense hydrilla (18 tons/acre).

Potential for Harvested Biomass Use

One cannot help being impressed by the vast renewable biomass resource present in hydrilla and waterhyacinth growths in Florida. While it appears as a major problem today, its enormity is indicative of the potential of this publicly owned resource. The Limnos system and the model subsequently described provide an efficient means of harvesting major quantities of plant biomass and a method of quantifying production and costs, important steps in the development of economic uses.

A Computer Model for Systems Analysis

A model of the Limnos Harvesting System was developed and programmed on a small desktop computer. This model facilitates the understanding of the effects of variation in the several parameters affecting system performance.

The computer model is useful also as a management tool. Although careful interpretation of the assumptions of the model is required, the manager could determine the optimum values for the parameters based on the constraints of an actual harvest location. Since the model estimates the effective capacity of the system and the utilization of the engines, it is possible to calculate the costs associated with a particular harvesting operation.

The model

The program logic for the overall harvesting operation is shown in Figure 2. The program is written in BASIC language and is described briefly below.

Model input. The parameters required by the model are described in Table 1. In most cases, the values are taken from the data collected during the latter part of the testing and demonstration on the Withlacoochee River, Florida. Various pieces of data were arranged and some interpretation was done to estimate the performance of the system. Parameter sensitivity analysis was conducted by varying these values in a range about the estimated value for this harvest situation.

Model output. The simulation subprogram at present keeps track of three important times: the total time to harvest the plot, the time the cutter/harvester is operating under load (harvesting and turning), and the time when a barge engine is loaded (transport and unloading). The total area covered is also accumulated but, at present, the program ensures that just the plot specified is cut so that the last pass of the cutter is adjusted to cut only that acreage left. The total acres then is just that specified. The program could be modified to keep other statistics. The driver program displays the three times as well as some other statistics it calculates. These include the percentages of total time that the engines are running and the system capacity both in areal rate and material (mass) rate.

Examples of the computer input and output are given in Figure 3.

In the example shown in Figure 3, the parameters input to the model are all fixed at the values shown in Table 1, with the exception of cutting width, which is considered to be 9 ft.

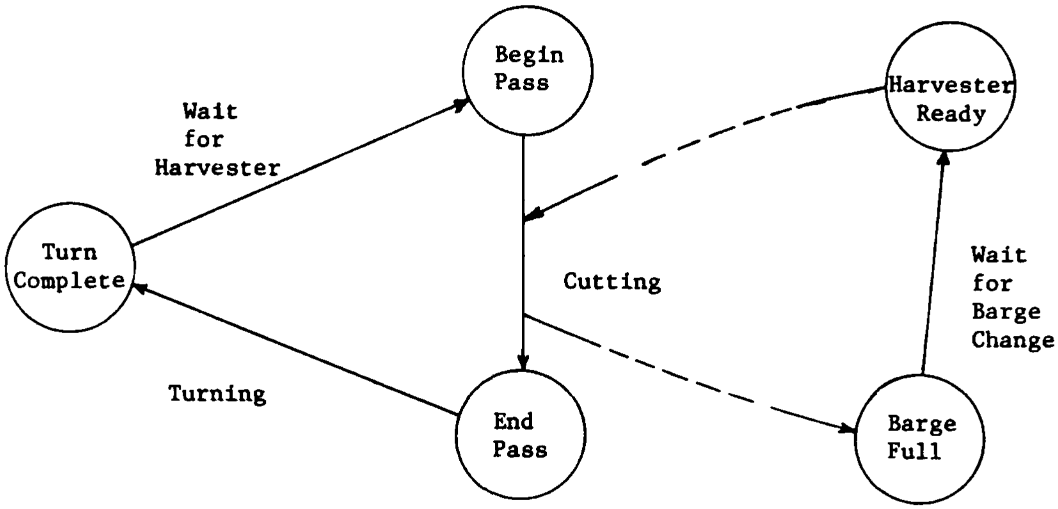
Capacity prediction

Using the computer model described above, it is possible to predict the overall capacity of the harvesting system for a specific set of conditions. The user can then estimate costs or attempt to adapt the operation for the most efficient harvest.

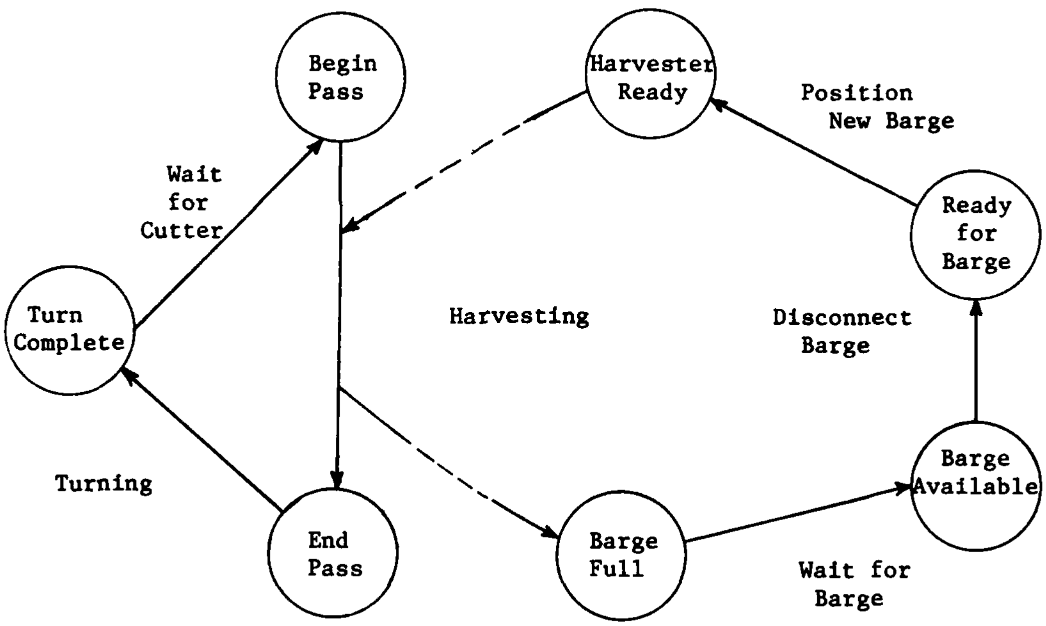
The model is capable of determining the interaction of any combination of the 14 parameters listed in Table 1. Since the possible combinations are numerous, several of the most significant ones, including weed density, harvester throughput, and hauling distance, would normally be selected for analyses.

Weed density. The weed density affects the width of cut so that the harvester throughput is maintained while the width of cut is below its maximum. This creates two distinct operating conditions.

a. For low density plots the cutter operates at maximum width and the harvester is operating at less than maximum throughput. The cutting rate essentially fixes the areal capacity and the weed density modifies the material (mass) capacity.



a. Cutting operations



b. Harvesting operations

Figure 2. Program logic diagrams of the Limnos Harvesting System

Table 1

Simulation Model Parameters

Symbol	Description	Value	Units
P1	Plot length	1000	ft
P2	Plot width	250	ft
P3	Hauling distance	1000	ft
D1	Weed density	18	tons/acre
S1	Harvester speed	220	ft/min
W1	Cutter width	16	ft
H1	Harvester throughput	50	tons/hr
T7	Harvester turn time	1.5	min
T8	Barge changing time	5	min
B0	Barge load	15	tons
B1	Barge speed loaded	450	ft/min
B2	Barge speed empty	700	ft/min
B4	Unloading rate	1	tons/min
B3	Additional dock time	6	min

plot size 1000 ft long × 250 ft
Hauling distance from corner of plot 1000 ft
Weed density 18 tons/acre

HARVESTER MAXIMUM SPEED-OPERATING 220 ft/min
MAXIMUM CUTTING WIDTH 16 ft
MAXIMUM GRINDER THRUPUT 50 tons/hr
actual speed 220 ft/min
acutal cutting width 9 ft

Harvester turning time 1.5 min
Barge changing time 5 min

BARGE LOAD 15 tons
SPEED -LOADED 450 ft/min
-EMPTY 700 ft/min
UNLOADING RATE 1 ton/min

Additional dock time 6 min

PROGRAM INPUTS

Time to harvest plot 191.7 min
Harvester engine util. 122.7 min (64 percent)
Barge engine utilization 97.7 min (51 percent)

Effective areal capacity 1.74 acres/hr

Effective material capacity 31.4 tons/hr

PROGRAM OUTPUTS

Figure 3. Example of computer input and output of a harvesting simulation

b. For high densities the harvester is limited in throughput and the cutter takes a narrower cut. The harvesting rate essentially fixes the material capacity while the areal capacity is modified by the weed density.

The critical density between those two conditions is given by:

$$\text{Density} = \frac{\text{Maximum Harvester Throughput}}{\text{Harvesting Speed} \times \text{Maximum Cutter Width}} \tag{1}$$

In Figure 4, the solid line shows this effect. As expected, high densities reduce the harvesting systems coverage rate. The optimum efficiency occurs at the critical density (10.3 tons/acre) where both cutter and harvester are operating at capacity.

An alternative operating procedure is to always operate at the

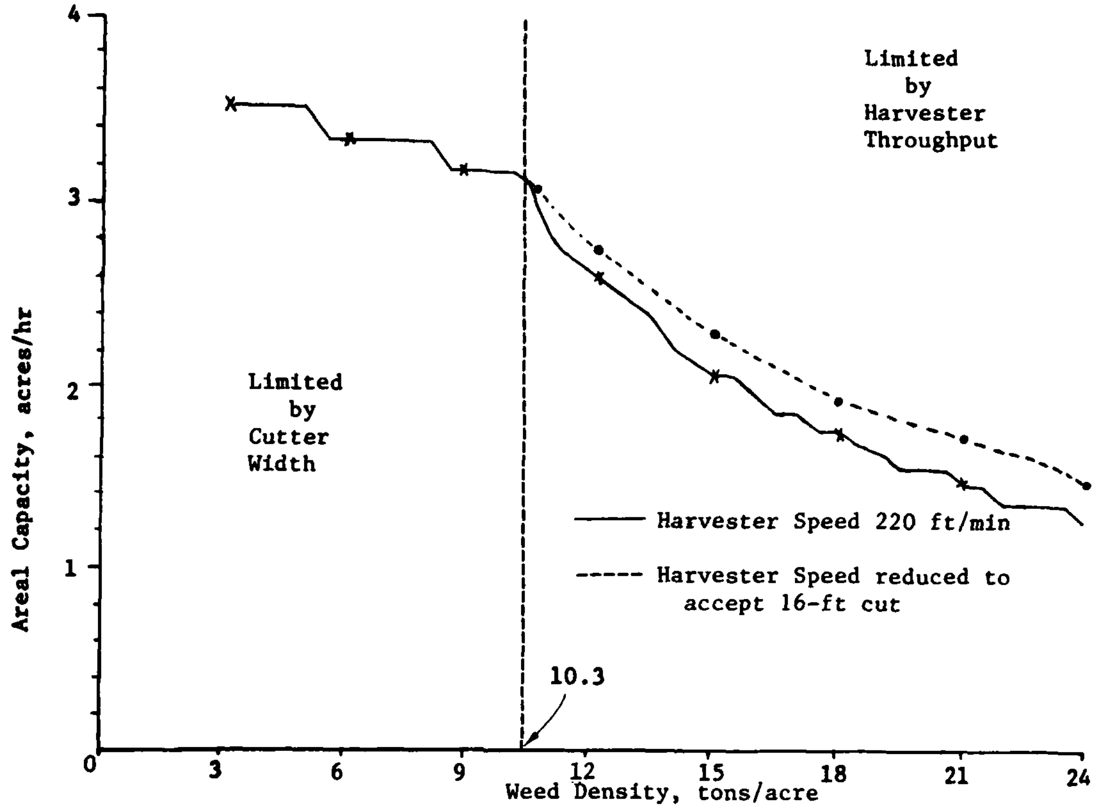


Figure 4. Effect of weed density on areal capacity

maximum cutting width but vary the speed of travel. In this case, the critical density would be:

$$\text{Density} = \frac{\text{Maximum Harvester Throughput}}{\text{Maximum Harvesting Speed} \times \text{Cutter Width}} \tag{2}$$

In Figure 4, the dotted line shows the effect of density with this operating practice.

Similar analyses may be made of effect on production of varying distances to landing sites, the size and shape of plots, or operating the equipment to cut only or cut, grind, and return.

A cost estimate. The following data are typical of the costs involved in the Limnos harvester operation. With a 1200-hr season and a 70 percent achievement (i.e. 70 percent of the total hours are spent doing actual harvesting), the harvesting system operates 840 hr. A machine capacity of 1.75 acres/hr (see Figure 4) allows 1470 acres to be harvested.

a. For a 10-year life with 10 percent interest rate
   Amortization = 0.26 × $120,000 = $31,200

b. Other overheads at 2 percent
   Other = 0.02 × $120,000 = $2,400

c. Repair as estimated
   Repair = $17,000

d. The fuel cost is based on using 3200 gal at a cost of $1.25/gal, which = $4,000

e. The labor cost is for five men at $40/hr
   For the season (1200 hr) = $48,000

Total Season Cost $102,600

Cost/hr = $122.14
Cost/acre = $69.80
Cost/ton = $3.88 (assuming a density of 18 tons/acre)

The above cost does not include travel and transportation for the crew operating the Limnos system.

Discussion

The model of the harvesting system has been parpared as a tool to improve the predictability of cost and production of mechanical control. While the foregoing analysis has been applied to the Limnos Harvesting System, it may also be used for other mechanical equipment to provide performance and cost data.

In programs where mechanical controls are to be used, a detailed management plan should be prepared in advance to achieve the greatest benefit:cost ratio for the program. The objective should be to prevent the development of an acute problem, thereby suggesting that control activities should commence before major plant growth is in evidence. The model indicates that harvesting at plant densities of 10 tons/acre or less would provide control at the least cost and that the cost of mechanical control increases significantly as the harvesting density increases.

The plan may include areas such as open water channels remote from landing sites where a cut, grind, and return operation is used, the cost of which is about 50 percent of full harvesting. Where long water or overland moves are required, they can be planned to minimize nonproductive time.

Where harvesting is to be conducted by a contractor, the method by which he finances capital costs will not be the same as a public agency who may purchase the equipment as a one time cost and budget only operating expenses thereafter. The contractor would require a short-term write-off of capital to which his overhead and profit would be added.

Nonetheless, a contract based on a firm hourly or acreage cost may be attractive as it provides for competition and would enable the control agency to make a choice based on both cost and environmental considerations.

Data have not been included for truck disposal of harvester production but may be estimated at $20/hr. Likewise, costs quoted are based on 1979 data and future estimates should include an increase of about 10 percent per annum to provide for changes in capital and operating expenses.

While experience in production and costs of harvesting is limited, there is a broad cost:benefit margin between the prices estimated and present herbicide costs for hydrilla. If economic uses are developed for the harvested biomass, significant cost reductions might be achieved, perhaps to the point where harvesting programs could be supported by the value of the biomass harvested.

PROBLEM IDENTIFICATION AND ASSESSMENT FOR AQUATIC PLANT MANAGEMENT

An Overview

by

Anthony M. B. Rekas*

Introduction

The U. S. Army Engineer Waterways Experiment Station (WES) has developed a concept for aquatic plant management that involves five basic elements, each implemented at various levels depending upon the magnitude of the aquatic plant problem.** These elements are: monitoring, reporting, treatment, public participation, and training. Monitoring is the application of methods for periodic identification and assessment of aquatic plant infestations in the problem area. Reporting is the application of systematic procedures for reporting pertinent information on aquatic plants to management. Treatment is the application of a spectrum of procedures to effect the desired level of control of aquatic plant infestations in any specified local environmental, social, or economic situation. Public participation is the implementation of a public information program to ensure public awareness of aquatic plant problems and proposed treatment programs and to elicit public cooperation. Training is the process of providing State and Federal personnel with the knowledge and techniques necessary to implement a successful management plan.

The problem identification and assessment work unit of the Aquatic Plant Control Research Program (APCRP) addresses several aspects of the monitoring and treatment elements of aquatic plant management (Hamilton 1977). Specifically, the work unit involves the development of rapid survey techniques to locate, identify, and map the distribution and character of problem emergent and submerged aquatic plant species, the development of a classification system to group the aquatic plant problem areas into categories related to available control techniques, and the development of techniques to assess the economic and social impacts of severe aquatic plant infestations as well as the economic and social benefits of effective control programs.

This paper presents a summary of the previous WES research on rapid survey techniques and the results of the 1979 water penetration tests with various films, discusses the progress to date on the user's manual for remote sensing of aquatic plants, discusses the progress on the

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** See Robert Lazor's paper, page 213.

classification system for aquatic plant problem areas, and outlines the planned approach to the development of assessment techniques for economic and social impacts of aquatic weed infestations.

Rapid Survey Techniques

Summary of research

Since 1976, the WES research on rapid survey techniques has been designed to: (a) determine the feasibility of using existing remote sensing systems to acquire data on the areal distribution of specific plant species and a quantitative categorization of their biomass (Link and Long 1977); (b) develop and evaluate aerial photography mission specifications (Link 1976); (c) identify and evaluate image intrepretation techniques (Long 1979); and (d) develop and evaluate methods of presenting the information for operational use.

The WES findings with regard to existing remote sensing systems are presented in Table 1. At the present time, we can recommend that black and white imagery be used for regional surveys, color imagery be used for detailed submerged aquatic plant surveys, and color infrared (IR) imagery be used for detailed emergent aquatic plant surveys.

1979 water penetration tests

A portion of the WES 1979 research work was devoted to the determination of which photographic film should be recommended for submerged aquatic plant identification. Field reports from several Districts had indicated problems with the previous recommendation of color IR film with a yellow filter (Wratten No. 12), overexposed one f-stop. The problems included the need for film temperature control in storage, use, and processing (contractors did not have cameras with internal temperature controls); the determination of the exact overexposure to use; and the past experience of both contractors and photointerpreters with color IR film.

Since the WES had planned to conduct periodic photographic surveys of several lakes in the State of Washington in connection with our work for the prevention of the spread of Eurasian watermilfoil (*Myriophyllum spicatum* L.) for the Seattle District, a plan was prepared to test the water penetration capability of three films, black and white (Kodak Double-X Aerographic Film, 2405), color (Kodak Ektachrome EF Aerographic Film, SO397), and color IR (Kodak Aerochrome Infrared Film, 2443). Specifications for the remote sensing mission are presented in Table 2. The films were tested for their capability to detect two sizes and two colors of targets that were diver-placed in three lakes at 5-ft depth intervals from 0- to 30-ft depths (Table 3). The results, which represent three photointerpreters' opinions on the maximum depth that the targets could be detected with 1:5000-scale imagery and 10X magnification, are presented in Table 4. It should be noted that water transparency and background color may significantly alter the maximum depths that targets can be detected; however, these results are consistent with

those reported by Lockwood et al. (1974) for similar film/filter combinations.

Users Manual for Remote Sensing of Aquatic Plants

Methodology

An operational methodology was developed involving six sequential steps (Table 5) whereby the user could plan, execute, and analyze the results of a remote sensing mission (Williamson, Dornbusch, and Grabau 1974). Work from 1976 to date has emphasized the refinement of basic aerial sensing procedures for use in aquatic plant management. Link and Long (1977) and Long (1979) have previously reported their findings with respect to the problem specification, ground control, data acquisition, and planning remote sensing missions and data acquisition steps. The primary emphasis of WES research efforts this past year was directed at detailing the procedures to be used in the last three steps: data transformation, information extraction, and information presentation for aquatic plant management.

Data transformation procedures. Data transformation involves putting the information obtained by the remote sensor system into a form suitable for analysis or interpretation. Factors that affect the amount of data transformation required include the method of interpretation to be used, the desired accuracy, and the form of the data product to be presented. The WES has concluded that the classical manual method of photo interpretation is recommended for aquatic plant surveys. The primary reason for this conclusion is based on the fact that automated interpretation procedures depend upon the capability of the instruments to distinguish aquatic plants from background based on their spectral (tonal) characteristics (versus the other image characteristics listed below):

- a. Shape.
- b. Dimension.
- c. Tone.
- d. Texture.
- e. Pattern.
- f. Location.
- g. Associations.

WES research has indicated that the spectral properties alone are not sufficient to distinguish specific aquatic plant species from background or other aquatic plant species and that texture, pattern, and associations characteristics of the plant species are often required for accurate image interpretation. Accuracy requirements depend upon the use of the final product and the form of the final product. District and

Division personnel have indicated that the areal distribution of aquatic plants is the primary type of desired information and that map products showing plant distribution by species in a waterbody are the desired form of this information. Additionally, the total acres of water surface covered and a quantitative categorization of the biomass of each aquatic plant species are desirable for planning aquatic plant control measures.

Based on the above discussion, the WES-recommended data transformation procedures are to produce a controlled photo mosaic of the entire waterbody (to reduce image distortion and scale changes in the imagery) and make a transparent film outline of the waterbody (i.e., a base map from the controlled photo mosaic) on which the interpreted distribution of the aquatic plant species will be subsequently displayed. United States Geological Survey (USGS) maps have been found to contain too many inaccuracies, particularly with respect to recent man-made structures and other modifications in waterbodies, to be used for base map purposes. It should be noted that the cost of a controlled photo mosaic is not insignificant. A controlled photo mosaic (1:24,000 scale) of Lake Seminole (37,000 acres) was produced for $6,000 (1978).

Data extraction. The WES-recommended manual method for data extraction includes the following procedures:

a. Interpret the outlines of the areal distribution of the aquatic plant species from the original imagery and trace onto transparent drafting film.

b. Transfer the outlined distributions to the drafting film base map using a Bausch and Lomb Zoom Transfer Scope (ZTS).

c. Verify the accuracy of the interpreted distributions using the original groundtruth data or (preferably) by taking the interpretated base map to the field and verifying the distributions.

d. Determine the total acres of water surface covered by the aquatic plant species by use of Bruning Areagraph Charts (dot-count method).

The procedures described above were developed after several attempts at using alternative procedures. The main limitation to direct transfer using the ZTS from the original imagery to the base map with any of the films is that the boundaries of the submersed aquatic plant distributions are very indistinct. While they can be seen (with suitable magnification) on the original imagery using a light table, the imagery is usually too dark to see the boundaries using the ZTS. Image distortion and scale changes on the original imagery are eliminated when the outlined boundaries (which are easily seen) are transferred to the drafting film outline of the base map using the stretch and magnification features of the ZTS. The drafting film outline of the base map is preferred because it can subsequently be overlaid onto the controlled photo mosaic to show distribution of aquatic plants with respect to other

topographic and cultural features. Changes in the distribution of aquatic plant species over a period of years in the waterbody can be easily determined by comparing (overlaying) the yearly distributions on the drafting films on a light table. The outlined distributions can be transferred directly to the controlled photo mosaic (rather than to drafting film), but the resulting map does not have the flexibility of analysis that a separate overlay allows. Groundtruth of the interpreted boundaries is essential to the further use of the map. Errors introduced by the interpretation process or by the transfer to the base map can be eliminated by adequate groundtruth data. The WES has developed an automated procedure to determine the area within a boundary, compute the sum of individually classified areas for an entire waterbody, and prepare a final map product; however, the procedure involves digitizing the boundaries of delineated areas and classifying each bounded area manually. The automated procedure is more accurate than the manual procedure (using the Bruning Areagraph charts), but does require the use of a digital converter and a skilled operator to take full advantage of the procedure.

Data presentation. As previously stated, the usual product required by the user is a map that accurately presents the areal distribution of aquatic plant species in a particular waterbody. Such a map can be used for planning aquatic plant control operations. Additional information that can be produced includes the total acres of surface area covered by the plant species.

Status of the user's manual

As a result of the 1979 work, the WES has completed the first stage of investigation into the systematic application of remote sensing techniques to specific aquatic plant management problems (i.e., techniques for using remote sensing for regional and detailed surveys of specific aquatic plant species). A draft user's manual is being prepared for use by operations personnel at the District and Division level.

Planned Rapid Survey Research

Additional WES research will be conducted to develop techniques for mapping the more difficult-to-obtain parameters such as plant density and growth stage. The WES has purchased two aquatic plant biomass samplers for use in determining plant biomass. One of these samplers was used to take biomass samples of Eurasian watermilfoil in the three Washington state lakes that were covered by the aerial photographic missions in 1979. Analysis has begun by WES of the biomass data; WES will attempt to correlate the biomass data with specific imagery characteristics. If successful, the plant species, its distribution, and plant biomass distribution could be determined from aerial imagery for use in planning aquatic plant control operations. One anticipated use of biomass data for aquatic plant control is the determination of the amount of herbicide necessary to order for each application season.

High plant biomass in an area would indicate the need to apply an aquatic herbicide at the maximum allowable rate in that portion of the waterbody. Thus, a map showing the distribution of selected levels of plant biomass could be used to determine application rates per surface acres of each level of plant biomass. These data could then be used to calculate the total amount (pounds of active ingredient) of herbicide necessary to order for each application season. An additional use of plant biomass data is to plan the sequence of control operations. An area with high plant biomass and heavy recreational use would probably be considered a candidate for early treatment in deference to an area with low plant biomass and little recreational use. The final research effort will involve development of a cost-effective, rapid, automated data extraction and display capability for Corps-wide use.

Classification System Development

Work was initiated by WES on this aspect of the Problem Identification and Assessment work unit in 1979. This work involved the identification and environmental factors that affect the performance of available control techniques and equipment. Efforts by WES were greatly aided by a list of environmental and resource factors presented by Joyce (1977) as shown in Table 6. Development of the classification system will continue in 1980 with the grouping (classification) of the various factors into a system for describing the differences between the environmental factors in an area and the development of the correlation between the classification system and available aquatic plant control resources.

Development of Assessment Techniques

The approach for developing a rational method of assessing the economic and social impacts of aquatic plants will be to develop a comprehensive assessment plan that will include the identification of areas with reported economic or social impacts due to aquatic plant infestations, the determination that differences in levels of plant infestations can be correlated to the perceived impacts, the development of a plan of study to quantify the impacts, and the development of procedures to obtain the necessary data. The data from several study sites will be used to establish the specific relationships between aquatic plant infestations and resulting social and economic losses on a cost-per-unit-of-infestation basis. Following normal Corps control operations at these sites, the benefits of the control operations will be determined by applying the same analysis procedures to document the decrease in social and economic losses.

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Table 1

Sensing Systems and Application to Aquatic Plant Management

Sensing System	Application* Regional Surveys	Detailed Surveys	Emergent Plants	Submerged Plants	Remarks
LANDSAT	+	0	+	0	The usefulness of this system is presently limited by the minimum size of the resolution element (approximately 1 acre) and difficulty in obtaining a "clean signature" for specific aquatic plant species
Thermal infrared	0	0	0	0	This system has two serious limitations: it is not readily available to operations personnel and it is extremely costly
Side-looking radar	0	0	0	0	This system has several limitations: it is not readily available to operations personnel, it has a minimum resolution of 50 ft, and it is extremely costly
Aerial photography					
Black and white	++	++	++	++	Black and white photography is the least expensive method to cover large areas, but is more difficult to interpret than color imagery. Color is easy to interpret, easy to handle, and has excellent water penetration capability. Color IR has produced the best contrast for emergent plants, but is extremely difficult to handle in use (temperature control); interpretation requires trained photo interpreters; and it does not have as much capability to penetrate water as color or black and white film
Color	++	++	++	+++	
Color infrared	++	++	+++	++	

* 0 = not suitable; + = limited suitability; ++ = suitable; +++ = optimal suitability.

Table 2

Specifications for the Remote Sensing Mission

Camera:	Zeiss RMK-A with 6-in. Zeiss lens
Film types:	Color: Kodak Ektrachrome EF Aerographic (S0397) Color Infrared: Kodak Aerochrome Infrared (2443) Black and White: Kodak Double-X Aerographic (2405)
Filter:	Color film - None, Color IR - Zeiss R, Black and white - Zeiss A
Time of day:	Between 10:00 a.m. and 2:00 p.m.
Cloud cover:	Less than 10 percent
Altitudes:	2,500 ft (1:5,000 scale) 5,000 ft (1:10,000 scale) 10,000 ft (1:20,000 scale)
Exposure:	Optimum land exposure
Forward and side overlap:	60 percent forward and 30 percent side

Table 3

Target Specifications and Placement

Target Type	Target Size	Target Colors	Water Depth to Targets, ft
Plywood panel	4 ft × 4 ft	White, green	0, 5, 10, 15, 20, 25, 30
Concrete block	16 in. × 8 in.	White, green	0, 5, 10, 15, 20, 25, 30

Table 4

Water Penetration Test Results, 1:5000 Scale Imagery

		Detection Limit (water depth, ft)			
		White		Green	
Site	Film	Panel	Block	Panel	Block
Lake Osoyoos	Color	20	15	15	10
(Secchi disc - 12 ft,	Color infrared	20	10	5	0
background - sand)	Black and white	20	10	10	0
Lake Sammamish	Color	15	10	10	5
(Secchi disc - 14 ft,	Color infrared	15	10	0	0
background - sand)	Black and white	10	5	0	0
Lake Whatcom	Color	15	10	5	0
(Secchi disc - 16 ft,	Color infrared	15	10	0	0
background - mud)	Black and white	15	10	0	0

Table 5

Steps Required for Application of Remote Sensing Techniques to Aquatic Plant Management

Step	Identification
1	Problem specification: What problem needs to be solved, what are the specific kinds of information necessary to solve it, and can a remote sensing system be used to obtain any or all of the needed information?
2	Ground control data acquisition and planning remote sensing missions: What types of ground control data are necessary to plan the remote sensing mission, what is the best sensor system to use, and what are pertinent mission profile parameters?
3	Data acquisition: Actual process of collecting ground control data and remote sensing imagery. This step may interact periodically with Step 2.
4	Data transformation: Putting the data obtained by the remote sensing system into a form suitable for analysis or interpretation.
5	Information extraction: Performing the analysis or interpretation to obtain the needed data from the product of the remote sensing system.
6	Information presentation: Putting the extracted data into a form in which it can be used to assist in solving the problem at hand.

Table 6

Data Requirements for Planning Control Programs*

Environmental Factors
Aquatic plant species present
Existing and potential population level of aquatic plants
Morphology of waterbody
Streamflow (seasonal and daily trends)
Weather (seasonal and daily trends)
Obstructions (man-made and natural)
Collection points for plants
Environmental constraints (critical fish and wildlife habitat, sensitive crops, etc.)
Uses of the waterbody (crop irrigation, water intakes, etc.)
Resource Factors
Man power (in-house, contract, or hired labor)
Available control methods (biological, chemical, mechanical)
Funds (operation and maintenance, special need)
Equipment requirements (boats, sprayers, harvestors, etc.)

* Modified from Joyce (1977).

NATURAL SUCCESSION OF AQUATIC PLANTS

Environmental Factors Affecting the Growth and Succession of Aquatic Plants

by

John W. Barko*

Introduction

The concept of succession derives from the early studies of terrestrial plant communities by Cowles (1899, 1901) and Clements (1916, 1936), who first described it as a universal process of directional change in vegetative community structure. More recently, succession has been further elucidated from an ecosystem perspective (Odum 1969), necessitating that functional--in addition to structural--changes be considered. In a classical sense, lentic aquatic ecosystems undergo succession as they change from deep, open water systems to shallower systems, due to accumulations of sediment and organic matter, until a fully terrestrial condition is attained (Wetzel 1975). Classical succession in most lakes occurs slowly over geological time and thus is difficult to study except in paleolimnological terms.

Another type of succession, referred to as cyclic (Krebs 1972), occurs over brief periods of time and is essentially nondirectional. These cyclic changes are superimposed upon ordinal changes inevitably wrought as a consequence of classical (or long-term) ecological succession. Cyclic changes in plant communities result from short-term (natural or man-induced) variations in the physical, chemical, or biotic environment. Patterns of explosive aquatic plant growth followed by their declining abundance observed for species such as *Myriophyllum spicatum* in North America (Carpenter 1979) and *Elodea canadensis* in Europe (Sculthorpe 1967) represent a form of cyclic succession. Short-term changes in the composition of aquatic plant communities promoted by the implementation of various control practices represent another form of cyclic succession.

The strengths and weaknesses of different species relative to environmental conditions ultimately control plant succession. Whenever a system becomes disturbed, the competitive equilibrium among species is changed, and they re-sort themselves in accordance with an altered set of environmental conditions. The ability to predict the outcome of this re-sorting process assumes the following crucial capabilities:

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a. An understanding of major environmental factors affecting plant growth, species composition, and succession.

b. An ability to quantitatively detect changes in various parametric aspects of these major factors.

c. A knowledge of the range over which these factors and associated parameters independently and interactively influence different aquatic plant species.

Our present understanding of environmental factors affecting the growth of aquatic plants is somewhat rudimentary, but is currently being expanded through various experimental research programs. Available measurement and analytical capabilities with regard to most aquatic-environmental parameters far exceed our current ability to interpret the data. This problem is well demonstrated by our present inability to readily translate information on changing environmental conditions (i.e., temperature, light, nutrients, etc.) into anticipated effects on aquatic plants.

Distinction Between Life Forms

The influence of various environmental factors on aquatic plants can be most clearly addressed by first considering the ecologically important distinctions between aquatic plant life forms (Sculthorpe 1967). Life forms of aquatic plants include (a) free-floating (e.g., duckweed), (b) floating-leaved (e.g., waterlily), (c) emergent (e.g., giant cutgrass), and (d) submersed (e.g., milfoil). Members of the last three categories (emergent, floating-leaved, and submersed plants) are rooted and attached to a substratum. Free-floating plants often have roots, but these do not function in attachment. Emergent aquatic plants, although adapted to constant or periodic standing water, are most similar to terrestrial plants. These have easily distinguishable and functionally separable aerial and rooted portions. Submersed plants are the most highly adapted to the aquatic environment. These plants remain totally submersed throughout their life span, lack structural rigidity, and therefore are dependent upon the buoyancy of the water for their support. Floating-leaved plants are intermediate in form between emergent and submersed life forms and have characteristics of both. Similar to the emergent aquatic plants, floating-leaved plants possess separate aerial and rooted portions. In addition to large floating leaves, smaller leaves, similar to those of submersed plants, are often produced by floating-leaved plants at the sediment surface.

Each of these life forms is specifically adapted to cope best with different aspects of the aquatic environment and consequently vary in their response to changes in environmental conditions. Thus, the spatial orientation of plant communities within the aquatic ecosystem and their demands on the environment differ considerably. These differences are reflected in the typical zonation of life forms in aquatic systems from

emergent vegetation in shallow areas, through floating-leaved vegetation at intermediate depths, to submersed vegetation in deep water (Wetzel 1975). Albeit this zonation tends to lessen competition among life forms, competition for environmental resources among species of a similar life form can be intense.

Physical and Chemical Factors

Light of wavelengths between approximately 390 and 760 nm is used by aquatic plants in photosynthesis. This range represents the violet to red portion of the visible light spectrum. In general, the penetration of different wavelengths of light into natural water depends upon the quantity and kinds of dissolved materials and suspended particulate materials that differentially absorb and scatter portions of the light spectrum. In many lakes, light penetration is significantly limited by turbidity associated with suspended sediment. The same effect can occur during phytoplankton blooms that frequently become dense enough in enriched situations to limit submersed aquatic plant growth (Jupp and Spence 1977).

Owing to the differential shade tolerances of submersed plant species, both their growth and zonation are affected by light availability (Spence and Chrystal 1970a,b; Bowes et al. 1977a). Investigations of the comparative light relations of submersed plants (Haller and Sutton 1975; Titus and Adams 1979) have demonstrated strong competition for light by coexisting species. The importance of this competition in affecting successional changes in the distribution and composition of aquatic plants in perturbed systems has recently prompted much needed investigation of the photosynthetic characteristics of several species (Van, Haller, and Bowes, 1976; Bowes et al. 1977a,b, among other studies).

Water temperature affects rates of various biochemical processes in plants. In general, overall carbon metabolism (i.e., plant growth rate) is strongly influenced by temperature, and different species demonstrate characteristic thermal requirements (Sculthorpe 1967). Few data are available on either the temperature optima or thresholds of thermal tolerance for aquatic plants. The principal reason for this dearth of information stems from the inability in most investigations to separate the effects of temperature from those of light on plant growth.

Species introduced from tropical areas (e.g. *Eichhornia, Pistia,* and *Hydrilla*) can generally tolerate rather high temperatures. Water temperature has been demonstrated to be an important factor in tuber production by *Hydrilla verticillata* (Van, Haller, and Garrard 1978). This species, and *Myriophyllum spicatum* as well, photosynthesize maximally at relatively warm temperatures: 35°-36°C (Van, Haller, and Bowes 1976). *Myriophyllum* also grows in the arctic (Holmquist 1971)

and thus appears to be quite thermally flexible. In contrast, *Hydrilla* grows very poorly at water temperatures below 20°C (Barko and Smart 1981b, in preparation), which may explain its limited latitudinal distribution in the United States. Data of this nature for other introduced species are presently lacking and need to be obtained before the influence of this important environmental factor can be appropriately assessed.

The role of sediment in the nutrition of aquatic plants varies among life forms. However, the majority of vascular aquatic plants are rooted, and their growth and distribution are markedly affected by sediment characteristics. For the most part, regions of nutrient absorption depend upon the relative availability of nutrients with respect to the distribution of plant tissues having an absorptive capability. Therefore, floating plants are usually forced to derive nutrients from the water. Nutrient uptake by emergent plants, which have extensive root systems and little absorptive surface exposed to the water, occurs almost exclusively from the sediment. With submersed and floating-leaved plants, nutrients may be absorbed from either the sediment or the water (Denny 1972). However, recent evidence has suggested that their roots are functionally very similar to those of emergent plants (Bristow 1975). Therefore, because nutrient availability is usually greater in sediments than in water, sediments represent a potentially important source of nutrition to submersed and floating-leaved plants. The phosphorus nutrition of rooted submersed plants (Barko and Smart 1980) and floating-leaved plants (Twilley, Brinson, and Davis 1977) appears to be predominantly sediment based. Moreover, it now appears that rooted aquatic plants may be able to fulfill most nutritional requirements by absorbing nutrients from the sediment (Barko and Smart 1981a, in preparation).

With most aquatic plants, water chemistry, from a nutritional standpoint, is probably much less important than sediment chemistry. Obviously, floating plants (including *Ceratophyllum*) represent a notable exception to this statement because they usually have no direct contact with bottom sediments. Two important, but less emphasized, aspects of water chemistry are pH and alkalinity. As with temperature, both of these factors can directly or indirectly affect overall aquatic plant metabolism.

The floating species *Pistia* and *Eichhornia* apparently have discreet pH requirements that can influence the nature of competition between them (Chadwick and Obeid 1966; Tag El Seed 1978). This factor (i.e., pH) probably also influences interactions among other life forms, but there is no definitive information available in this regard.

In most freshwater systems, alkalinity is normally imparted by bicarbonate, carbonate, and hydroxyl ions. Alkaline systems demonstrate pH values exceeding 7.0 (neutrality) and tend to be buffered against dramatic pH change. In highly alkaline waters, there may be some selectivity for plant species that can utilize bicarbonate sources of inorganic carbon in photosynthesis because free CO_2 concentrations are low

(Wetzel 1975). In alkaline systems, plants must be further able to effectively withstand heavy carbonate precipitation and associated epiphyte development on their leaf surfaces. In nonalkaline (i.e., unbuffered) systems, plants must be adaptable to oftentimes dramatic diel variations in pH associated with changes in system metabolism. The species composition of acidic versus alkaline environments can differ markedly (Hutchinson 1975), yet there is little definitive information related to the underlying causes of such observations.

Biotic Factors

As indicated earlier, one of the key interactions between phytoplankton and rooted submersed plants involves competition for light. Similarly, the dense growth of attached (epiphytic) algae on the leaf surfaces of submersed plants can contribute to their decline (Phillips, Eminson, and Moss 1978). Dense populations of floating plants (duckweeds, hyacinths, etc.) may also competitively exclude submersed vegetation by reducing the depth of light penetration in water. Additionally, these floating plants compete for dissolved nutrients with the phytoplankton.

There are few data on allelopathy (i.e., chemical interference) among aquatic vascular plants. However, the influence of extracellular metabolites on algal species succession has been demonstrated by Keating (1977, 1978). The possible importance of similar allelochemical interactions among vascular aquatic plants has recently been suggested by Szczepanski (1977). There are many types of compounds involved in allelopathy. These include aldehydes, alkaloids, alcohols, amino acids, enzymes, glycosides, ketones, organic acids, vitamins, etc. Not all allelopathic substances are specific in their mode of action. Like herbicides, they can affect different aspects of plant growth (e.g., photosynthesis, respiration, cell division rate, ion uptake, membrane permeability, etc.), and may be poisonous to a variety of aquatic organisms. The role of allelochemical substances in aquatic plant succession can apparently be influenced by aqueous nutrition in the case of duckweed (Wolek 1974) and sediment nutrition in the case of emergent hydrophytes (Szczepanski and Szczepanski 1976). Research on allelopathy among aquatic plants is currently in its infancy, but may someday provide new perspectives in aquatic plant control.

Grazing is probably the most obvious biotic factor affecting aquatic plants. However, the quantity of aquatic plant tissue actually consumed in the living state by grazing animals (herbivores) is small, usually less than 10 percent of that produced (Wetzel 1975). Some introduced grazers such as the white amur are capable of consuming far greater quantities of plant mass than native grazers, and this capability has been implemented through their use in the control of aquatic vegetation (Sutton 1977; Mitzner 1978). Due to the apparently selective feeding habits of the white amur, its introduction can alter plant community

composition (Van Zon, Van der Zweerde, and Hoogers 1976; Fowler and Robson 1978). Such alterations have similarly been reported as a consequence of selective herbicide application (Hestand and Carter 1977) and lake drawdown (Hestand and Carter 1975). Unfortunately, these changes have not been predictable and the final outcome of various control procedures has oftentimes been unfavorable when the aquatic ecosystem is considered as a whole.

Conclusions and Ongoing Research

Conclusions

In aquatic ecosystems, particularly those affected by human activities, changes in plant community composition are often very rapid and have been essentially unpredictable. Even in terrestrial plant communities, where succession has been most intensively examined, there is still an inadequate understanding of the factors actually causing observed community changes. This same problem in aquatic systems has made it difficult or impossible to suggest manipulations to alleviate undesirable trends. Thus, algae blooms, for instance, remain an unavoidable consequence of increased pelagic nutrient enrichment. Before we can predict which species will replace others, either during natural or man-induced succession within aquatic plant communities, it is imperative to fully understand the influence of different environmental factors on aquatic plants, both singly and interactively. In the future it will become increasingly necessary to interface the information gained through definitive experimental work in these regards with laboratory and field investigations of aquatic plant control to ultimately develop a capability for predicting changes in plant community composition resulting from the implementation of different control practices.

Ongoing research

Research designed to increase our understanding of aquatic plant succession was initiated in 1979 with an investigation of the influence of temperature and light on the growth of the submersed species, *Egeria densa*, *Hydrilla verticillata*, and *Myriophyllum spicatum*. Statistical analyses of growth data (e.g., biomass, shoot density, height, internode spacing, photosynthesis, and respiration) indicate pronounced effects of both temperature and light on all three species over ranges common to aquatic systems. Similarly, in an earlier investigation (Barko and Smart 1980) supported by the WES Environmental Water Quality and Operational Studies Program (EWQOS), the significant influence of sediment characteristics on two of these species (*Hydrilla* and *Myriophyllum*) was noted.

During 1980, we plan to more discriminantly investigate the influence of sediment characteristics on the growth of rooted submersed plants. Additionally, we will utilize available information on the independent effects of light, temperature, and sediment to conduct an

investigation of the competitive relations among these three introduced species and their native counterparts under different combinations of the above conditions. During the conduct of these research efforts, we will rely heavily upon applicable environmental data currently being collected at various sites across the country where these species grow abundantly. This will enable us to establish realistic environmental gradients in our experimentation and to qualify the conclusions and recommendations forthcoming from these studies.

In the future, we will interface the information gained through our continuing experimental work with laboratory and field investigations of aquatic plant control to ultimately develop a capability for predicting changes in plant community composition resulting from the implementation of various control practices. Additionally, these data will input the development of conceptual and mathematical formulations for predicting the probability and mode of encroachment of introduced submersed plant species into presently noninfested aquatic systems.

Our recent work has exclusively involved rooted submersed plants. Excellent related research on this aquatic plant life form is currently being conducted by other agencies and at numerous universities. As emphasized earlier in this article, relatively little definitive information exists on the environmental requirements of other aquatic plant life forms. This remains an important area of needed research, in which we hope to initiate participation in the near future.

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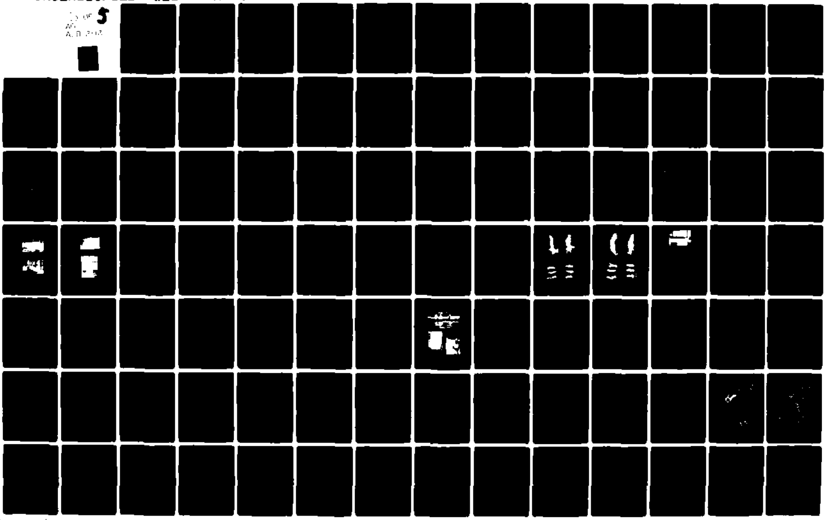

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LARGE-SCALE OPERATIONS MANAGEMENT TEST OF INSECTS AND PATHOGENS FOR CONTROL OF WATERHYACINTH IN LOUISIANA

An Overview

by

D. R. Sanders, Sr.*

Introduction

Waterhyacinth became a significant problem in Louisiana waterways during the 1890's. About 1900, a concerted effort was initiated to develop methods to provide relief from the rapidly expanding problem. The earliest efforts consisted primarily of mechanical systems aimed at the physical removal of the plants. Later, chemical methods (e.g. sodium arsenite) were employed for waterhyacinth control. About 1945, control emphasis was shifted to the use of 2,4-D, and this chemical remains today as a primary method of controlling waterhyacinth.

Although 2,4-D is very effective in controlling waterhyacinth in areas where the chemical can be applied by conventional ground or aerial application, much of the total waterhyacinth acreage in Louisiana is in backwater areas (e.g. swamps) that are not conducive to chemical control. During periods of high water, the waterhyacinths are flushed out of these nursery areas into the heavily utilized rivers, canals, and lakes, thus magnifying the problem. Clearly, a need exists to develop methods of controlling waterhyacinth in these backwater areas.

During the past 10 years, research conducted as part of the Biological Control Technology Development element of the Aquatic Plant Control Research Program (APCRP) has resulted in the discovery of several organisms capable of impacting waterhyacinth. Some of these organisms (e.g. *Neochetina eichhorniae*) have been cleared for use and were subsequently released in Louisiana. Others (e.g. *Sameodes albiguttalis*) have only recently been cleared for release. A fungal plant pathogen, *Cercospora rodmanii*, is ready for a large-scale field evaluation under the auspices of an Experimental Use Permit from the Environmental Protection Agency. Although these organisms have been individually evaluated at some level for potential as biocontrol agents of waterhyacinth, no large-scale field evaluation of combinations of these organisms has been attempted.

Faced with continuing problems with waterhyacinth proliferation

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in nursery areas, the New Orleans District (NOD) requested in 1979 that the U. S. Army Engineer Waterways Experiment Station (WES) conduct a Large-Scale Operations Management Test (LSOMT) of insects and pathogens for the control of waterhyacinth in Louisiana. With funds provided by the Office, Chief of Engineers, through NOD, the project was initiated in 1977. Details of the plan of tests are presented in WES Instruction Report A-79-1.

Purpose and Scope

The purpose of this study is to develop and demonstrate an operational capability for the use of selected combinations of insects and plant pathogens for the control of waterhyacinth in Louisiana.

The LSOMT will encompass all portions of the State of Louisiana where waterhyacinth is a problem. Study areas will be established in each of the nine major river basins in Louisiana.

Approach and Objectives

Test organisms

Based upon the results of previous research, the following organisms were selected for inclusion in the LSOMT:

a. *Neochetina eichhorniae* - this insect, the mottled waterhyacinth weevil, has already been released and is widely distributed on waterhyacinth in Louisiana. The Louisiana Department of Wildlife and Fisheries has been instrumental in distributing the weevil in Louisiana.

b. *Arzama densa* - a native noctuid moth, *Arzama densa* is devastating in its effects on waterhyacinth, but is very sporadic in occurrence, thereby rendering management of this insect extremely tentative.

c. *Sameodes albiguttalis* - a Pyralid moth introduced into this country from Argentina, *Sameodes* has not been released in Louisiana at the inception of this project. Mr. Theriot will discuss more about our work with *Sameodes* later.

d. *Cercospora rodmanii* - originally isolated from declining waterhyacinths in Rodman Reservoir in 1971, this host-specific fungal plant pathogen has since been developed to the product formulation stage by Abbott Laboratories. This formulation is ready for extensive field evaluation. The only introduction of *C. rodmanii* in Louisiana prior to the LSOMT was its inclusion in the Lake Concordia study performed by the WES from 1975 to 1977.

Approach

Due to diversity of the organisms involved, and the fact that not all species are at the same stage of operational development as a biocontrol agent, it is necessary to consider this LSOMT as being composed of several separate but interdependent sutdies, as follows:

- a. Pilot field study of *Cercospora rodmanii*.
- b. Efficacy test of the Abbott Laboratories (AL) formulation of *Cercospora rodmanii*.
- c. Evaluation of equipment for application of the AL formulation of *Cercospora rodmanii*.
- d. Evaluation of the large-scale field application of insect-pathogen combinations.
- e. Supportive studies (mass-rearing requirements for *A. densa)*.

With respect to the use of *C. rodmanii,* two distinct approaches will be evaluated in the LSOMT. The first approach involves point releases of the fungus to determine its ability to establish and spread by natural means and become epidemic on waterhyacinth over a large area. If successful, the need for the ability to mass-apply *C. rodmanii* would be obviated. The result would be a simple, economic method for the use of *C. rodmanii* as a biocontrol agent. The second approach involves the development and evaluation of a system for the mass application of the fungus. This consists of an attempt to artificially generate a localized epidemic through mass application of inoculum. The availability of such a system would permit targeting the use of *C. rodmanii* in areas of greatest concern.

The successful conduct of this LSOMT will, to a large degree, hinge on our ability to intermesh these studies to obtain data that will provide a rational basis for a recommendation of combinations of these biocontrol agents to operations personnel for field use. To obtain the data necessary to accomplish this goal, it will be necessary to define the population dynamics of both the target plant and the biocontrol agents. We must also be able to define the interactions of these organisms under field conditions. In addition, optimum treatment rates and mode of establishment of the respective biocontrol agents must be determined. Extraneous factors (e.g., weather, predators) and their effects on waterhyacinth and the biocontrol agents must be defined. Finally, a timetable must be developed for obtaining a given level of anticipated control after application of the combinations of agents by operations personnel. Such information will enable the operations personnel to more effectively integrate these biocontrol agents into their overall program of waterhyacinth management. To effectively transfer technology resulting from this LSOMT, an engineering manual will be prepared following completion of the study in 1983.

Objectives

Given the overall purpose and approach of the LSOMT, the following general objectives of this project are:

- a. To determine necessary and sufficient means for establishing effective populations of the test organisms in the field.
- b. To evaluate the effectiveness of the introduced combinations of species.
- c. To determine probable environmental limitations on the ability of these organisms to maintain effective field population levels.

Pilot Field Study of *Cercospora rodmanii*

Introduction

A pilot field study was initiated as part of the LSOMT in 1977 to determine if *C. rodmanii* would become established, thrive, and spread in Louisiana, thereby producing effects similar to those observed on waterhyacinth in Rodman Reservoir, Florida.

Objectives

The specific objectives of the pilot field study are:

- a. To determine appropriate methods for transplanting, disseminating, and establishing *C. rodmanii* in the field.
- b. To test the ability of the pathogen to develop to epidemic proportions from the point application of small quantities of inoculum.
- c. To develop appropriate monitoring and observation requirements for the large-scale test sites.
- d. To acquire familiarity with the basic phenology of waterhyacinth in the test area.

Procedure

After selection of suitable test sites and initial site characterizations, three sites were treated with *Cercospora*-infested plants in June 1977, and additional sites were treated with cultured wet mycelium in August 1977. The same application methods were used to treat additional sites in 1978.

Following treatment, the sites were inspected at approximately monthly intervals through the 1977, 1978, and 1979 growing seasons. Notes have been kept on the general condition of the plants, including height, growth stage, vigor, symptoms of disease, presence of insect activity, and general site conditions (e.g., water quality, water depth, and rate and direction of water flow). Specimens were collected

periodically for verification of the presence of *C. rodmanii*. In addition, observations were extensively documented with color photographs.

The data are currently being analyzed and a report is being prepared for publication in FY 80.

LARGE-SCALE OPERATIONS MANAGEMENT TEST OF INSECTS AND PATHOGENS FOR CONTROL OF WATERHYACINTH IN LOUISIANA

Progress Report of Field Applications

by

Russell F. Theriot*

Introduction

This portion of the LSOMT involves the application of *Neochetina, Cercospora,* and *Sameodes* at an operational level.

Purpose

The overall purpose of this part of the LSOMT is to obtain the data necessary to determine the feasibility of using selected combinations of insects and pathogens to control waterhyacinth on an operational basis in Louisiana.

Objectives

The specific objectives of the large-scale application test are:

a. To determine the most effective combination of biocontrol agents for the control of waterhyacinth in Louisiana.

b. To develop the framework for an operational system for the routine use of biological agents for control of waterhyacinth.

c. To assess the cost of implementation of the resulting operational system.

Approach

Test area and types

The State of Louisiana has been selected as the test area.

* U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

Louisiana has more than four million acres of fresh water, nearly all of which is potentially infestable by waterhyacinth. The state is drained by nine major river basins, all of which have substantial infestations of waterhyacinth.

Two basic types of field tests will be conducted, varying according to the size of test sites and degree of replication. In the replicated test, the efficacy of various treatment combinations of *Cercospora* and *Neochetina* and the effect of climate on effectiveness of the treatment combinations will be determined on 1-acre sites. In the unreplicated tests, sites ranging in size from 20 to 400 acres will be treated with various combinations of agents and application scenarios that would be difficult or impossible to duplicate within the time frame and scope of this LSOMT.

Test organisms

The organisms to be evaluated in this test include:

a. *Cercospora rodmanii* - plant pathogen.

b. *Neochetina eichhorniae* and *N. bruchi* - weevils.

c. *Sameodes albiguttalis* - moth.

d. *Arzama densa* - moth.

Replicated tests

To determine the effect of climate on efficacy of the various treatments, a random block design will be used. Each treatment will be replicated three times in each of the two blocks (north and south Louisiana) as follows:

Treatment	North Louisiana	South Louisiana
Cercospora only	3 sites	3 sites
Neochetina only	3 sites	3 sites
Cercospora and *Neochetina*	3 sites	3 sites
Untreated controls	3 sites	3 sites
	12 sites	12 sites

For the purposes of this test, the state was divided into north and south regions by using the northern boundaries of the Parishes of Beauregard, Allen, Evangeline, St. Landry, and Pointe Coupee as the dividing line. The resulting line generally divides the State of Louisiana topographically and climatologically. This delineation will permit us to evaluate the effects of different climate regimes on the activity of the biocontrol agents. To maximize the potential impact of *Cercospora* in the overall test area, at least one test site will be utilized in each major river basin where a suitable test site can be found.

With input from the New Orleans District and Louisiana Wildlife and Fisheries personnel, whose job it is to control in excess of one million acres of waterhyacinth in Louisiana, 60 potential test sites have been identified and are now being evaluated for possible use in the test.

After application of test organisms for each test site, data collection (Table 1) and evaluation will be conducted by a contractor. A Request for Proposals for this work was released on 2 November 1979 and responses will be evaluated in December 1979.

Thus far, we have 12 acceptable sites in south Louisiana and 6 in north Louisiana for the replicated test. Finding additional sites in north Louisiana this year has been difficult. Although north Louisiana historically has had a waterhyacinth problem, the April census of acres infested has been reduced from 35,000 in 1975 to 10,800 in 1978. Inspection of this area during the spring and summer of 1978 revealed no more than 300 total acres of waterhyacinth north of Alexandria. It is possible we will have to modify the test to reduce the number of sites in north Louisiana.

Unreplicated tests

Purpose. The purpose of these tests is to demonstrate the effectiveness of combinations of biocontrol agents and application scenarios when applied at a scale (20 to 400 acres) that is not feasible for replication.

Objective. Specific objectives of the unreplicated tests include:

a. To determine the effectiveness of the commercial formulation of *Cercospora* when applied in summer or fall.

b. To determine the effectiveness of multiple applications of the commercial formulation of *Cercospora*.

c. To determine the effectiveness of a *Cercospora/Arzama* agent combination in controlling waterhyacinth.

d. To establish *Sameodes albiguttalis* in Louisiana.

e. To determine the effectiveness of a *Cercospora/Sameodes* agent combination in controlling waterhyacinth.

Test scenarios. Six separate tests will be conducted during the LSOMT. These are as follows:

a. *Cercospora* applied in summer.

b. *Cercospora* applied in fall.

c. Multiple applications of *Cercospora* (spring, summer, and fall).

d. *Cercospora/Arzama*.

e. *Sameodes*.

f. *Cercospora/Sameodes*.

Table 1

Data Collection

Major Data Categories	Specific Parameters	Sampling Interval
Target plant (waterhyacinth)	Abundance Biomass Reproduction - sexual and asexual Plant vigor Height Root length Number of petioles	Pretreatment; 4, 8, and 12 weeks posttreatment; then quarterly thereafter
Test organisms *Neochetina* spp.	Population density Population conditions Number of individuals at each stage (adult, larvae, pupae) Spatial distribution Impact on target plant (feeding scars and larvae tunnels)	
Cercospora rodmanii	Infectivity (propagules per leaf) Verification of *Cercospora* Pathogenicity (leaf damage index)	
Other organisms impacting target plant	Population density Population condition Number of individuals at each stage (adult, larvae, pupae)	
Arthropods (insects and mites)	Spatial distribution Impact on target plant (feeding scars) (larvae tunnels)	
Pathogens (viral, bacterial, fungal)	Pathogenicity (leaf damage index) Identification of organisms producing described symptoms	
General system qualities	Geographic location Perimeter description Water inflow and outflow Backshore land use Water depth	Initially Initially Initially Initially Pretreatment; 4, 8, and 12 weeks posttreatment; then quarterly thereafter
Water quality	Water temperature pH Dissolved oxygen Hardness Total phosphorus Total organic nitrogen Nitrate-nitrite Potassium Ammonia Salinity	Pretreatment; 4, 8, and 12 weeks posttreatment; then quarterly thereafter Initially
Meteorology	Rainfall Air temperature Frost days Relative humidity Wind velocity and direction	Monthly from nearest official weather station Monthly from nearest official weather station

Data collection, analysis, and portrayal. The basic parameters, procedures, and timing for data collection, analysis, and portrayal will be the same as were used in the replicated test. Major data categories and frequency of sampling will be the same for each test. Onsite monitoring will be accomplished by WES personnel.

Supportive studies

During the course of the preliminary and exploratory studies leading to the formulation of this LSOMT, several problems were revealed relating to aspects of the biology of the organisms that directly affect their value as biocontrol agents for waterhyacinth or an eventual management of them for that purpose.

One such study in which we are engaged is the study regarding requirements for the artificial rearing of *Arzama densa*. *Arzama* is a native noctuid moth that causes considerable damage to waterhyacinth when found in fairly large numbers. The problem with *Arzama* is that it is found only sporadically and usually in small numbers. After reviewing some of the successes that the U. S. Department of Agriculture (USDA) has had in mass-rearing insects for control of pests, the WES has funded the USDA Southern Weed Science Laboratory, Stoneville, Mississippi, to develop methods for culturing *A. densa* in an artificial environment for timed mass releases in the field.

In view of the observed destructiveness of the individual *Arzama* larvae on waterhyacinth, it would be advantageous to release this insect en masse on sites where the waterhyacinth is insufficiently impacted by natural populations of other insects or pathogens, or in seasons unfavorable for the natural regeneration of this or other insects in the field. Further, early-season *Arzama* releases, before the waterhyacinth has attained significant biomass, may inflict proportionally greater damage to the waterhyacinth. This could result in increased effectiveness of *Neochetina* and *Cercospora*.

Summary

In summarizing the progress of the LSOMT since January of this year, we have accomplished the following:

a. The test plan has been written, published, and approved.

b. Of the 24 replicated test sites, 18 have been preliminarily chosen.

c. *Sameodes* has been introduced into Louisiana and evidence of reproduction has been noted.

d. The spring efficacy test has been completed and a report written and sent to Abbott Laboratories, who petitioned EPA on 31 October 1979 for an Experimental Use Permit. Approval is expected within the next 6 months.

e. The fall efficacy test and equipment evaluation test have been conducted and the data are presently being analyzed.

f. A Request for Proposals for the data collections on replicated sites was published on 2 November 1979, and proposals will be evaluated in December 1979.

LARGE-SCALE OPERATIONS MANAGEMENT TEST OF INSECTS AND PATHOGENS FOR CONTROL OF WATERHYACINTH IN LOUISIANA

Preliminary Studies with *Cercospora rodmanii*

by

E. A. Theriot*

Introduction

The plant pathogen *Cercospora rodmanii* was isolated from declining waterhyacinth plants on Rodman Reservoir in 1973 by Dr. Conway at the University of Florida. The University was given patent rights to the organism by the U. S. Army Corps of Engineers, and Abbott Laboratories (AL) has been granted the rights to develop a commercial product form for sale and distribution. One of the pathogens to be evaluated in the LSOMT in Louisiana will be this formulation.

Objectives

The objectives of these studies are:

a. To evaluate the infectivity and pathogenicity of the AL *C. rodmanii* formulation.

b. To establish treatment rates to be used in spring and fall applications of the large-scale field test in FY 80 in Louisiana.

c. To evaluate conventional commercial application equipment to apply the formulation.

Spring Efficacy Test

Procedure

Fifteen test tanks with a 1-m^2 surface area were lined with a double layer of polyethylene to prevent a toxic reaction by the water-hyacinth from the galvanized coating of the tanks. The tanks were

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* U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

then filled with tap water, and the water levels were maintained at 15 cm from the top of the tanks for the duration of the test. Nutrient solution was added to each tank to ensure that plant growth was not limited by a nutrient deficiency. The test tanks were placed in three general areas on the WES grounds, five tanks to an area, and the tanks were separated by a minimum distance of 100 m to prevent cross-contamination.

A remote weather station was positioned at one tank for the duration of the spring study. This station recorded the air temperature and relative humidity in the waterhyacinth canopy, the wind direction and velocity, and the tank and water temperatures on an hourly basis.

To measure the effects of the *Cercospora* formulation on the growth of waterhyacinth, the newest emergent leaf of six plants was tagged. This made it possible to discriminate between original plant tissue that received direct application and new untreated tissues in the tanks.

The AL formulation of *C. rodmanii*, a wettable powder containing 10^6 viable propagules/gram, was applied at rates of 5, 10, and 20 g/m^2. In addition, there were two sets of controls: one set was untreated, and the other was treated with the growth substrate contained in the formulation. Each treatment rate and control was replicated three times.

Treatments were randomly allocated to test tanks within each of the test areas. A hand-held sprayer was used to apply the formulation. Following application, the tanks were covered with a sheet of plywood for a 24-hr period due to the threat of rain. This ensured the presence of the inoculum on the leaf surface for a sufficient time to initiate infection.

Data were collected from each tank 1 day prior to treatment; post-treatment data were collected at 3 days and 1, 2, 4, and 6 weeks after treatment. The data included the number of new emergent leaves on the original plants, the number of dead leaves, and the number of daughter plants. To determine the effects of *C. rodmanii* on waterhyacinth, the disease index/leaf was determined by the use of the scale of 1-10 developed by Dr. Conway* (Table 1). A value of 1 represented a leaf with no apparent symptoms; a value of 10 indicated a dead leaf and petiole. Values of 2-9 corresponded to increasing coverage of a leaf surface by disease symptoms. The values for disease damage reflected not only *C. rodmanii*, but also disease symptoms elicited by other organisms. The average disease index (ADI) for original leaves, new leaves, and leaves of daughter plants was also determined.

Results

Environmental conditions at the initiation of the test were less

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* Conway, K. W. 1976. "Evaluation of *Cercospora rodmanii* as a Biological Control of Waterhyacinth," Phytopathology, Vol 66, pp 914-917.

than optimal. Although relative humidity was 90 percent or higher during the majority of the 3-day period of initial infection, the ambient temperatures within the waterhyacinth canopy were within the optimal temperature range for *C. rodmanii* growth only 40 percent of the time (Figure 1).

Infectivity. Three days after treatment, it was observed that the formulation had successfully infected the waterhyacinth tissues in the treated tanks. Evaluation of the 3-day posttreatment data revealed statistically significantly higher ADI values in the treated tanks than in either controls (Table 2). However, the observed differences between the treatment rates were not statistically significant.

Pathogenicity. The leaves originally treated with the formulation continued to display statistically significant higher ADI values than the controls until 4 weeks posttreatment, after which the ADI values were virtually the same for all treatments. This was due to the fact that the majority of the original leaves in the test tanks had been replaced. Six weeks after application, no original leaves remained in any of the tanks.

Although the observed differences in ADI for the new emergent leaves on the original plants were not statistically significant for any evaluation period, values for the ADI were consistently higher in the treated tanks as compared to the controls (Table 3). Two weeks after application, there were fewer daughter plants in the treated tanks as compared to the controls, but the values were found not to be satistically significant (Table 4). Four weeks after application, the ADI values for the daughter plants were significantly higher in the treated tanks as compared to the controls.

One week after the final data collection, plant tissues were removed from each tank for examination. *C. rodmanii* was verified in tissues from the tanks treated with the formulation, but was not found in any of the tissues taken from the control tanks. The 100-m distance between test tanks proved to be sufficient to prevent cross-contamination for the 6-week period.

Conclusions

Conclusions from the study are:

a. The AL formulation of *C. rodmanii* is infectious on waterhyacinth tissues, even under less than optimal environmental conditions and on plants of high vigor.

b. The fungus was able to proliferate throughout waterhyacinth tissues following initial infection.

c. Secondary infection of new waterhyacinth tissues can be expected to occur after treatment.

d. A 5-g/m^2 treatment rate was sufficient to achieve adequate infectivity for a spring application.

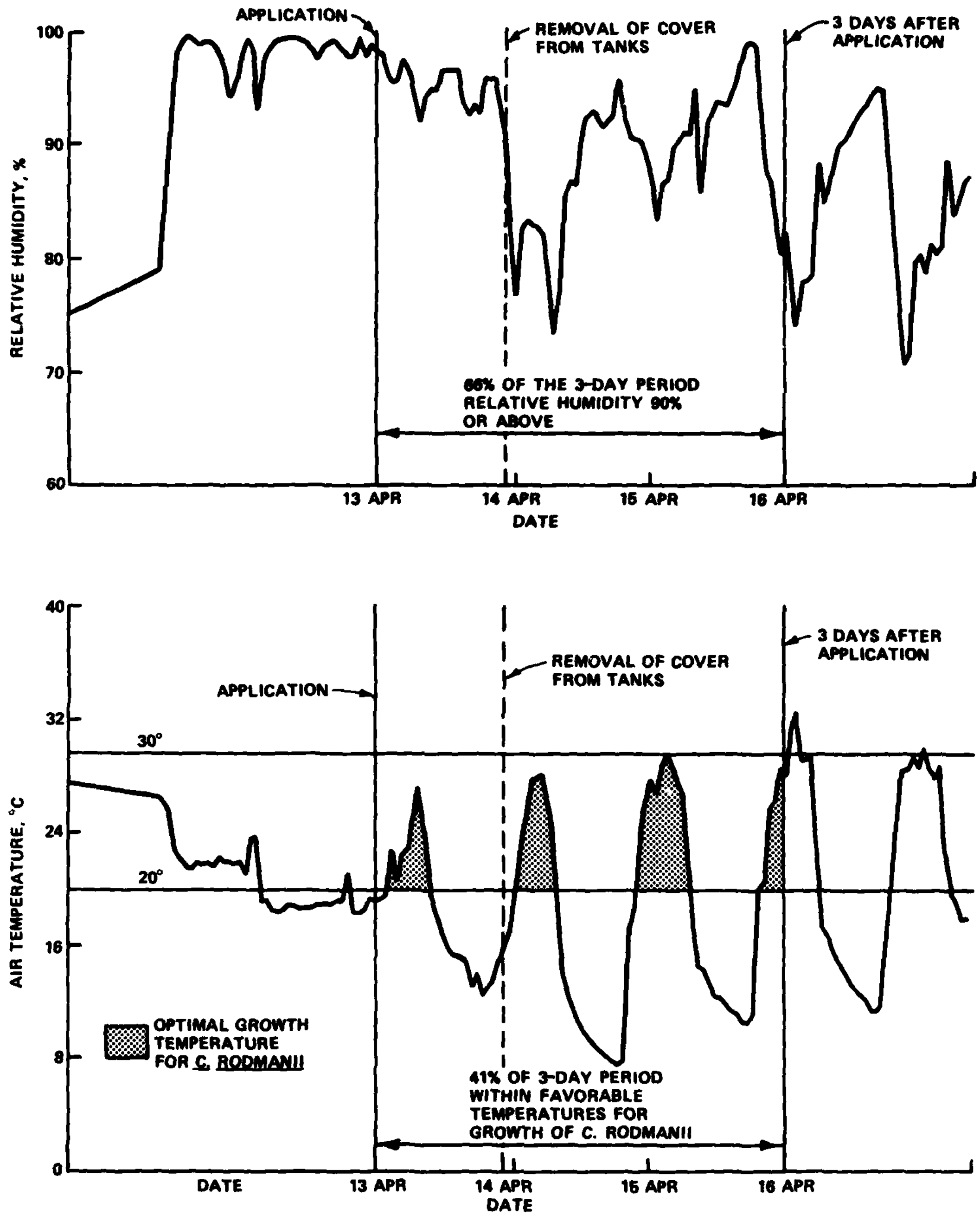


Figure 1. Canopy air temperature and relative humidity during the period of infection of waterhyacinth by *C. rodmanii*

Fall Efficacy Test

Procedure

The AL formulation for the fall study, containing 4×10^6 viable propagules/gram, was applied at rates of 1, 2.5, 5, and 10 g/m^2. Since there was no significant difference between the treated and untreated controls in the spring test, only an untreated control was used in the fall test. Otherwise, procedures were the same as for the spring test.

Because the last data collection date was 20 November 1979, the data have not been evaluated. However, typical *C. rodmanii* symptoms manifested themselves on the waterhyacinth tissues approximately 2 weeks earlier than in the spring test. This is believed to be due to the more favorable temperatures for growth of *C. rodmanii* during the initial infection period.

Equipment Evaluation Study

Objectives

The objectives of this study are:

a. To determine methods of application and equipment that can be used in the large-scale field application test.

b. To verify the infectivity of the AL formulation of *C. rodmanii* on waterhyacinth in the field.

c. To compare growth and disease advancement of *C. rodmanii* on waterhyacinth in Louisiana with Dr. Conway's results in Florida.

Procedure

Test site. A test site near Laplace, Louisiana, was selected for this study, and fifteen 21-m^2 plots were established, three blocks of five plots per block. Plots were separated by a distance of 100 m. While the obvious advantage of using conventional herbicide spray equipment to apply *C. rodmanii* was recognized, it was also realized that the high pressure pump could possibly destroy the fungal cells. To assess this possibility, treatments included the AL formulation with 1×10^4 viable propagules/gram at a rate of 5 g/m^2 applied at 150 psi with a John Bean Roadside Spray unit with a piston-driven pump, and an impeller-driven transfer pump at 20 to 25 psi. Also, a set of control plots for each type of equipment were sprayed with tap water. Additional plots were treated with cultured wet mycelia of *C. rodmanii* applied by the transfer pump at a rate of 50 g/m^2. This was the same rate used by Dr. Conway in earlier studies with the fungus. Each treatment was replicated three times. The test was initiated on 19 September 1979.

Data collection. Data were collected prior to treatment and at 2, 4, and 7 weeks after treatment. Twelve plants were randomly selected from each plot on each sampling date by using water shoes. The disease index was determined for each leaf, and ADI values were determined for each plant and test plot. Root lengths and plant heights were determined prior to application and on the final sampling date.

Results

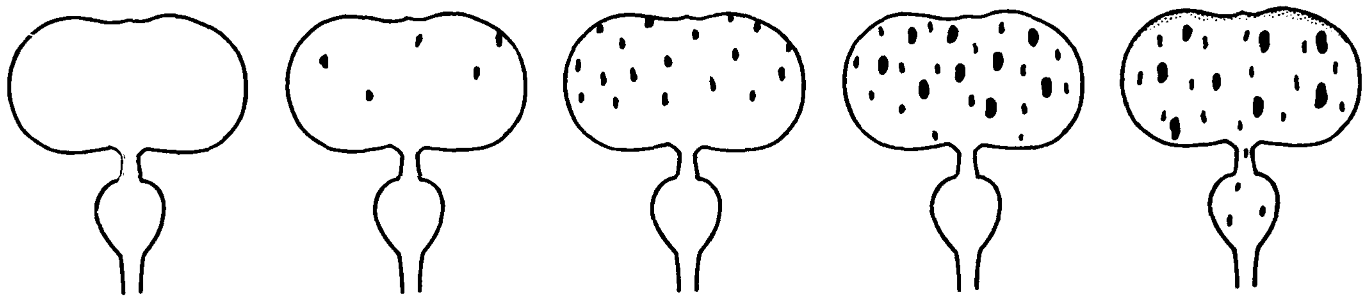
The data have been collected, but analysis of the data has not been completed. However, tissues were collected from each plot at 4 and 7 weeks posttreatment, and *C. rodmanii* has been isolated from plots treated with the AL formulation and the wet mycelium. The fungus was not isolated from tissue samples from control plots. To further verify the ability of the fungal cells to survive the high pressures of the application equipment, samples were taken directly from the spray nozzles on the day of application. *Cercospora rodmanii* was isolated from samples from each type of equipment. Therefore, it has been demonstrated that the AL formulation of *C. rodmanii* can be applied with conventional herbicide application equipment.

Summary

The potential of the AL formulation of *Cercospora rodmanii* as a biocontrol agent of waterhyacinth has been clearly demonstrated in these tests. The formulation will be tested further for compatibility with adjuvants, surfactants, and nutrient media to enhance its survival and infectivity on the leaf surface.

Table 1. DISEASE INDEX FOR DAMAGE TO LEAVES OF WATERHYACINTH BY CERCOSPORA RODMANII

NUMERICAL RATING SYMPTOMS	1	2	3	4	5
	NO SPOTS ON LEAF OR PETIOLE.	1-4 SPOTS ON LEAF, NO PETIOLAR SPOTTING.	LESS THAN 25% OF LEAF SURFACE WITH SPOTS, NO COALESCENCE OR PETIOLAR SPOTTING.	LESS THAN 50% OF LEAF SURFACE WITH SPOTS, SOME COALESCENCE, NO PETIOLAR SPOTTING.	LESS THAN 25% OF LEAF SURFACE WITH SPOTS, COALESCENCE, SOME TIP-DIEBACK AND PETIOLAR SPOTS.



	6	7	8	9	10
	LESS THAN 50% OF LEAF SURFACE WITH SPOTS, COALESCENCE, 10% TIP-DIEBACK, PETIOLE SPOTTING.	LESS THAN 75% SPOTS, COALESCENCE, (30%) TIP-DIEBACK, INCREASING PETIOLAR SPOTTING.	GREATER THAN 75% SPOTS, COALESCENCE, (60%) TIP-DIEBACK, COALESCING SPOTS ON PETIOLE.	DEAD LEAF BLADE, PETIOLE GREEN, BUT HEAVILY SPOTTED.	DEAD LEAF BLADE AND PETIOLE (SUBMERGED).

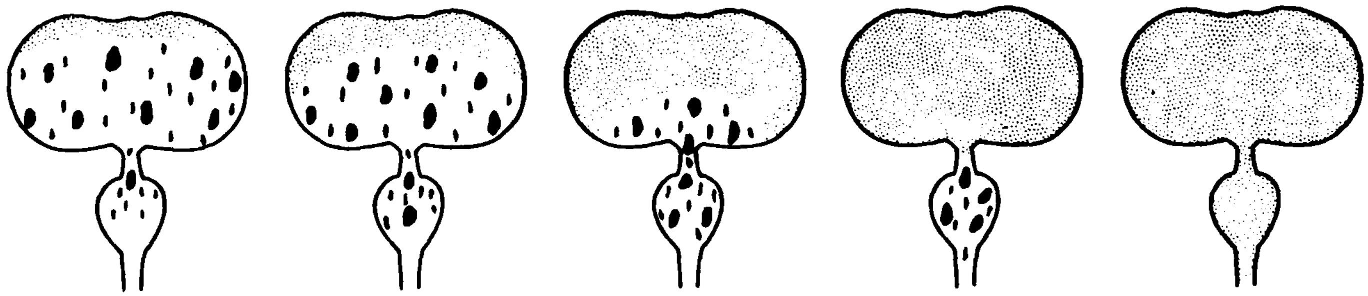


Table 2

Average Disease Index Per Leaf for Original Waterhyacinth Tissues After Treatment with Three Rates of *Cercospora rodmanii* and the Carrier Substrate*

Treatment Rate	Time, days					
	0	3	7	14	28	42
0 (control)	1.19 a	1.57 a	2.07 a	2.88 a	8.71 a	10.00 a
0 (substrate)	1.21 a	1.77 a	2.52 a	3.37 a	8.76 a	9.92 a
5 g/m^2	1.17 a	2.21 b	2.98 b	4.05 b	8.99 a	10.00 a
10 g/m^2	1.18 a	2.56 b	3.35 b	4.28 b	8.92 a	10.00 a
20 g/m^2	2.27 a	2.68 b	3.53 b	4.67 b	9.29 a	10.00 a

* Means within a column followed by the same letter are not significantly different at the 5 percent level as judged by Duncan's Multiple Range Test.

Table 3

Average Disease Index Per Leaf for Emergent Leaves of Original Waterhyacinth Plants After Treatment with with Three Rates of *Cercospora rodmanii* and the Carrier Substrate*

Treatment Rate	Time, days					
	0	3	7	14	28	42
0 (control)	NA**	NA	1.17 a	1.33 a	2.49 a	4.21 a
0 (substrate)	NA	NA	1.21 a	1.27 a	2.36 a	3.62 a
5 g/m^2	NA	NA	1.31 a	1.72 a	2.80 a	4.71 a
10 g/m^2	NA	NA	1.44 a	1.57 a	2.97 a	4.74 a
20 g/m^2	NA	NA	1.32 a	1.48 a	2.91 a	4.78 a

* Means within a column followed by the same letter are not significantly different at the 5 percent level as judged by Duncan's Multiple Range Test.

** NA = Not applicable because there were no emergent leaves on this date.

Table 4

Average Disease Index Per Leaf for Daughter Plants After Treatment with Three Rates of *Cercospora rodmanii* and the Carrier Substrate*

Treatment Rate	Time, days					
	0	3	7	14	28	42
0 (control)	NA**	NA	1.00 a	1.50 a	2.60 a	4.60 a
0 (substrate)	NA	NA	1.10 a	1.47 a	2.96 a	4.40 a
5 g/m^2	NA	NA	1.07 a	1.93 a	3.43 b	4.47 a
10 g/m^2	NA	NA	1.00 a	1.53 a	3.47 b	4.83 a
20 g/m^2	NA	NA	1.07 a	1.80 a	3.97 b	4.07 a

* Means within a column followed by the same letter are not significantly different at the 5 percent level as judged by Duncan's Multiple Range Test.

** NA = Not applicable because there were no daughter plants.

LARGE-SCALE OPERATIONS MANAGEMENT TEST TO EVALUATE PREVENTION METHODOLOGY FOR CONTROL OF EURASIAN WATERMILFOIL IN WASHINGTON

Prevention as an Aquatic Plant Management Method

by

R. L. Lazor* and E. A. Dardeau, Jr.*

Introduction

In cooperation with the U. S. Army Engineer District, Seattle (NPS), WES has initiated a LSOMT to evaluate the concept of prevention as an operational technique for managing problem aquatic macrophytes in the State of Washington. The primary objective of the LSOMT is to prevent the submersed aquatic macrophyte, Eurasian watermilfoil (*Myriophyllum spicatum* L.), from reaching problem-level proportions in selected water bodies within that state.** Eurasian watermilfoil, a member of the plant family Haloragaceae, was first introduced into North America in the nineteenth century. Since 1960 it has rapidly spread across North America and has reached problem levels in most water bodies where it has become established.† Its broad ecological amplitude has enabled it to adapt well to spring, fluvial, lacustrine, and estuarine ecosystems in the United States and Canada.

LSOMT

The WES developed a LSOMT designed to provide the data that would result in the identification of prevention methodologies that can be implemented to prevent Eurasian watermilfoil from reaching problem-level proportions. Component plans of the LSOMT were developed to include the following elements:

a. Test site selection plan.

b. Monitoring (surveying) plan.

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* U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

** U. S. Army Engineer Waterways Experiment Station, CE. 1979. Large-scale operations management test to evaluate prevention methodology. Draft Work Statement, Vicksburg, Mississippi.

† Elser, H. J. 1969. Observations on the decline of the watermilfoil and other aquatic plants, Maryland, 1962-1967. Hyacinth Control Journal 8(1)52-60.

c. Reporting plan.

d. Treatment plan.

e. Public awareness plan.

f. Training plan.

The preliminary results of the 1979 field tests under each component plan are discussed herein.

Preliminary Results of 1979 Field Tests

Test site selection

The NPS selected 13 water bodies for evaluation as candidate test sites. Through joint NPS-WES coordination, the five test sites shown in Figure 1 were selected, based on the following criteria: (a) presence of Eurasian watermilfoil; (b) encompassing both fluvial and lacustrine ecosystems; (c) encompassing a typical range of environmental conditions found in eastern and western Washington; and (d) encompassing Category I, II, and III designations as follows:

a. Category I (Prevention). Low problem levels that are in close proximity to documented infestations and are, therefore, vulnerable to potential infestation.

b. Category II (Maintenance). Small areas with problem-level occurrence of Eurasian watermilfoil and with a large area of potential infestation.

c. Category III (Control). Extensive infestations that significantly impact user interests.

The sites chosen were:

a. Lake Osoyoos - a 5729-acre (2036 acres in the United States) natural lake on the Okanogan* River (Okanogan River Miles 79.0-90.0) (a tributary of the Columbia River) located on the United States-Canadian border in Okanogan County, Washington, and in British Columbia. Category I (Prevention).

b. Okanogan River - also located in Okanogan County. Reach selected as a test site is that between Zosel Milldam (Mile 77.4) and the downstream end of Lake Osoyoos (Mile 79.0). Category I (Prevention).

c. Lake Whatcom - a 5029-acre natural lake located in Whatcom County, Washington. Serves as the principal water supply for the City of Bellingham. Category II (Maintenance).

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* This river name is spelled "Okanagan" in Canada.

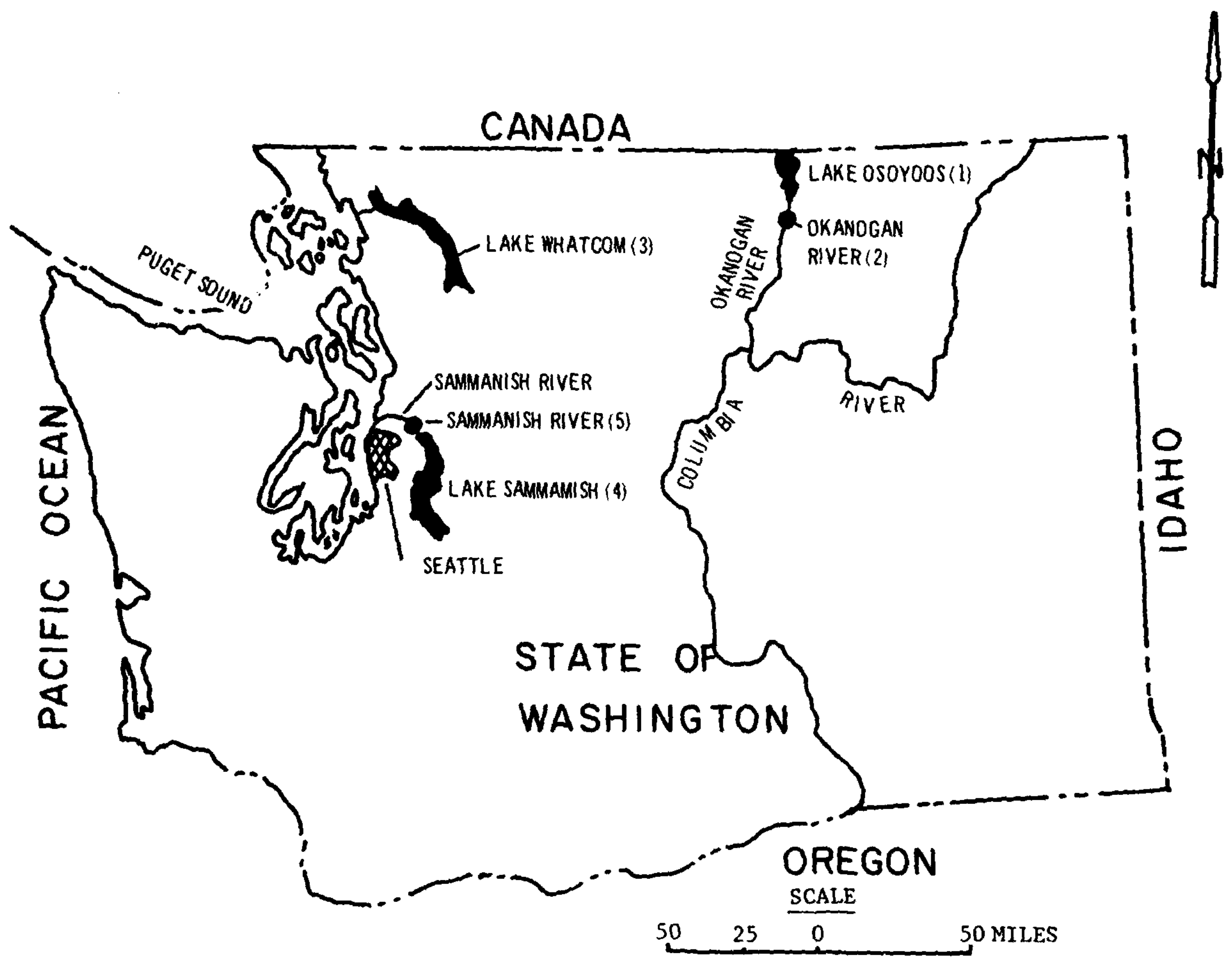

Figure 1. Locations of test sites on Lake Osoyoos, Okanogan River, Lake Whatcom, Lake Sammamish, and Sammamish River in the State of Washington

d. Lake Sammamish - a 4897-acre natural lake located approximately 13 miles east of Seattle, in King County, Washington. Category III (Control).

e. Sammamish River - also located in King County. Outlet of Lake Sammamish and drains directly into Lake Washington. Reach that encompasses the test site extends from the Lake Sammish outlet (Mile 15.3) downstream to the Highway overpass at Marymoor Park (Mile 14.4). Category II (Maintenance).

Monitoring

At each of the three lacustrine test sites, professional divers made underwater observations to determine the maximum depths of Eurasian watermilfoil occurrence. These depth limits were plotted on topographic maps and overlays to color aerial photographs at a scale of 1:10,000 to 1:20,000. In the summer of 1979, survey teams used this information to make further onsite inspections by boat to map the areal distribution of Eurasian watermilfoil in these three lakes between the shoreline and the maximum depth of occurrence. The field teams mapped the boundaries of each colony. Colony boundaries were established using fathometer surveys supplemented by information supplied by the divers. Below are the pertinent data on Eurasian watermilfoil at each lacustrine test site:

Lacustrine Test Site	Maximum Depth of Occurrence, ft	Potential Infestable Area, acres	Infested Area 1979, acres
Lake Osoyoos	25	425*	38*
Lake Whatcom	25	506	15
Lake Sammamish	35	928	135

* Does not include Canada.

Underwater surveys were not conducted at the two fluvial test sites since water depths were less than 25 ft and the assumption was made that Eurasian watermilfoil potentially could occur throughout the area.

Ground truth data collection. Interpretations of aerial photography are useful in establishing plant colony locations and determining changes in configurations of colony boundaries over time, but do not provide information on plant density or the amount of biomass present in a plant population. The WES approached the problem by attempting to characterize the aquatic plant populations of Lakes Osoyoos, Whatcom, and Sammamish in terms of their biomass. Maps and remote imagery of Lakes Osoyoos, Whatcom, and Sammamish were overlaid with grids, and random numbers of grid squares were selected on each. The WES field teams then used the WES biomass sampler to sample all the selected grid squares. This sampler collected all aquatic vegetative material inside a 0.25-m^2 column that extended from the surface of the water to the

lake bottom. Team members measured depths, identified all plants, made wet weight determinations, and counted meristems with each sample. The biomass values for Eurasian watermilfoil found in the sampled grid squares were then used to compute the biomass of this species in the three water bodies. The following tabulation is the total and unit biomass values that were determined for Lake Osoyoos, Lake Whatcom, and Lake Sammamish:

Lacustrine Test Site	Total Biomass lb*	Unit Biomass lb/acre*
Lake Osoyoos**	62,629	147.4
Lake Whatcom	37,026	73.2
Lake Sammamish	4,130,287	45,432.7

* Using wet weights and considering only that area of water body inside maximum depth of occurrence.

** Does not include Canada.

From the wet weights, numbers of meristems, and depth values collected in each 0.25-cm^2 column of water, the biomass-density (i.e., wet weight/unit volume) and meristem-density (i.e., number of meristems/unit volume) determinations could then be made. Table 1 shows the ranges of biomass and meristem density values for the grid squares containing Eurasian watermilfoil in each lake.

Remote-sensing missions. In the summer and early fall of 1979, NPS and the WES scheduled:

a. Operational missions - to map the extent of the areal coverage of Eurasian watermilfoil in the three lacustrine test sites.

b. Experimental missions - to evaluate interpretation techniques for identifying small developing colonies of this submersed aquatic macrophyte species.

Missions were flown with the following film-filter combinations:

a. Black and white. Kodak Double-X Aerographic (2405); Zeiss A filter.

b. Color. Kodak Ektachrome EF Aerographic (SO397); no filter.

c. Color infrared. Kodak Aerochrome Infrared (2443); Zeiss R filter.

Many areas that appeared to contain submersed aquatic vegetation were tentatively marked but had to be field checked for verification of the presence of Eurasian watermilfoil. Often areas of dead organic material were confused with the problem colonies. Remote imagery did, however, adequately serve to supplement the ground truth surveys in this study.

As a part of the remote-sensing effort of the LSOMT, missions were flown over Lake Osoyoos, Lake Whatcom, and Lake Sammamish to determine the limits of feasible detection depths for underwater target panels and blocks. The target panels were 4- by 4-ft sheets of plywood painted white or green and placed at 5-ft depth increments from the water surface to a depth of 30 ft while the target blocks were 16- by 18-in. blocks of concrete painted the same colors and placed at the same depth increments. Table 2 gives the results of the target-detection effort for the three types of 1:5000-scale imagery with a 10X magnification; it shows that the color film (SO397) proved to be the best overall in terms of its water penetration capability at all three test sites.

Reporting

The WES performed a study and analysis of reporting techniques in use by other agencies. A draft report* of the findings of the study has been prepared.

Treatment

During 1979, two mechanical treatments of Eurasian watermilfoil were implemented. These treatments included the erection of a barrier system on the Okanogan River and a hand-pulling exercise on both the Okanogan River and Lake Osoyoos. Each is discussed below.

Barrier system. In late July 1979, the NPS constructed a barrier system consisting of debris, operational, and evaluation barriers across a 290-ft-wide cross section of the Okanogan River, 0.1 mile downstream from the Cherry Street Bridge at Oroville, Washington. Cost (1979) for design, construction, operation, and maintenance was $95,000. This system was operated for a 12-week period until mid-October of that year. Below is a description of the three barriers:

a. Debris barrier. Large open-mesh barrier designed to intercept large floating debris (e.g., logs) upstream from the operational barrier. Extends from slightly above the water surface to within 3 ft of the streambed (to permit migration of anadromous fishes).

b. Operational barrier. Large fine-mesh structure intended to collect fragments of Eurasian watermilfoil. Top is placed in the same position (with respect to the water surface) and has approximately the same dimensions as the debris barrier.

c. Evaluation barriers. Two barriers, each having five sets of six vertically arranged 1-ft^2 net sections that extend from slightly above the elevation of the water surface to the elevation of the streambed. One elevation barrier

* Hogg, E. A. 1979. Inventory and assessment of current methods for managing aquatic plant information. Draft Miscellaneous Paper. U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

(No. 1) was placed upstream from, and the other (No. 2) downstream from the debris and operational barriers. These barriers were designed to evaluate the effectiveness of the operational barrier at removing Eurasian watermilfoil fragments from a water body.

Wet weights of the vegetative material collected on the operational barrier were obtained, and average weekly percentages of Eurasian watermilfoil were determined from those found in several representative samples. Total wet weight of vegetative material declined but the percentage of Eurasian watermilfoil found in the samples increased each week. During the first week (29 July-4 August), the height of the growing season, only 5.2 percent (by wet weight) of the total quantity of vegetative material collected was Eurasian watermilfoil, whereas in the twelfth week (14-20 October), when fragmentation was in progress, the percentage had reached 34.8.

The evaluation barriers were in place for 11 weeks, their last week of operation being 7-13 October 1979. Evaluation barrier No. 1 served as the control for the experiment. An overwhelming majority of the material collected on the control barrier (No. 1) was intercepted on or in the net sections sampling the 0- to 1-ft depth range. Although lesser total weights were collected each week on the downstream barrier (No. 2), these weights had a more even vertical distribution, indicating that the operational barrier was performing as designed and that some fragments had passed beneath the operational barrier. Analyses of the effectiveness of the barrier system are shown in Table 3. Effectiveness values ranged from a low of 23.5 percent during week No. 7 (9-15 September) to a high of 85.6 percent during week No. 5 (26 August-1 September). The average weekly effectiveness was 62.2 percent.

Hand-pulling exercise. During late summer 1979, a WES field team conducted a special exercise designed to evaluate the efficiency of small-scale hand removal of Eurasian watermilfoil at two test plots on the Okanogan River (Nos. 1 and 2) and one test plot on Lake Osoyoos (No. 3). The following tabulation includes the descriptions of the test plots:

	Test Plot		
	No. 1	No. 2	No. 3
Area treated, ft^2	1470	612	150
Estimate percent Eurasian watermilfoil coverage	25	35	30
Average depth, ft	2.5	3.0	3.0
Bottom sediment	Silt (over gravel)	Sand and gravel	Silt (in crevices between pieces of stone riprap)*
Underwater visibility	Poor	Good	Good

* Test plot was located on the submerged portion of a stone breakwater.

The test plots were enclosed with 0.25-in. mesh capture nets attached to floats. The team measured and characterized each of the test plots, recorded numbers of man-hours, recorded wet weights, and made estimates of percent success (in terms of areal coverage) of the areas cleared and of percent root removal at each sample site. Table 4 summarizes the results of this 1979 exercise.

Public awareness

The WES has participated in four NPS-sponsored public meetings, two radio interviews, and in the publication of two newspaper articles. Another important area of WES contribution has been in the preparation of NPS information brochures for the public. The WES coordinated all publicity activities of the LSOMT with the Chief, Public Affairs Office, NPS.

Training

Two aquatic plant management workshops were conducted by the WES in cooperation with the NPS during the summer and fall of 1979 for planning, engineering, and operational staff of Federal, State, and local agencies in the State of Washington. The workshops provided primary training that emphasized aquatic plant identification and reproductive biology, monitoring, and treatment techniques.

Table 1

Biomass Density and Meristem Density Values of Eurasian Watermilfoil in Lake Osoyoos, Lake Whatcom, and Lake Sammamish

Test Site	Number of Grid Points Sampled	Number of Grid Points Containing Eurasian Watermilfoil	Biomass Density Values for Grid Samples Containing Eurasian Watermilfoil g wet wt/m^3			Meristem Density Values for Grid Squares Containing Eurasian Watermilfoil no/m^3		
			Maximum	Mean	Minimum	Maximum	Mean	Minimum
Lake Osoyoos	145	11	394	55	1.5	135	19	0
Lake Whatcom	146	12	93	14	0.7	103	15	0
Lake Sammamish	99	34	2782	279	0.4	907	132	0

Table 2

Detection of Underwater Target Panels and Blocks on 1:5000-Scale Imagery

Test Site	Film	Detection Limit (Water Depth), ft			
		White		Green	
		Panel	Block	Panel	Block
Lake Osoyoos (Secchi disk - 12 ft, background - sand)	Color	20	15	15	10
	Color infrared	20	10	5	0
	Black and white	20	10	10	0
Lake Sammamish (Secchi disk - 14 ft, background - sand)	Color	15	10	10	5
	Color infrared	15	10	0	0
	Black and white	10	5	0	0
Lake Whatcom (Secchi disk - 16 ft, background - mud)	Color	15	10	5	0
	Color infrared	15	10	0	0
	Black and white	15	10	0	0

Table 3

Percent Effectiveness of the Barrier System, Okanogan River, Oroville, Washington: 29 July-13 October 1979

Week No.	Total Wet Weights of Vegetative Material Collected for Entire Okanogan River Cross Section, g: Barrier No. 1 (Upstream)	Barrier No. 2 (Downstream)	Percent Effectiveness of Barrier System $100\% - \frac{\text{Wet Wt No. 2}}{\text{Wet Wt No. 1}}$
1	5,750.6	1,173.3	79.6
2	4,602.4	751.1	83.7
3	5,117.8	801.2	84.3
4	2,523.8	443.5	82.4
5	2,412.3	347.3	85.6
6	9,737.3	3,082.7	64.7
7	5,984.7	4,578.0	23.5
8	10,442.4	4,896.1	53.1
9	7,752.9	4,380.5	67.9
10	6,884.7	2,490.1	59.3
11	7,268.1	2,954.6	59.3
Totals and average effectiveness	68,477.0	25,898.4	62.2

Table 4

Results of 1979 Eurasian Watermilfoil Hand-Pulling Exercise on the Okanogan River and Lake Osoyoos

	Sample Site		
	No. 1 Okanogan River	No. 2 Okanogan River	No. 3 Lake Osoyoos
No. of field personnel involved	4	3	2
Man-hours required for			
Setup	1.5	2.0	1.5
Dismantling	1.0	0.8	0.5
Hand-pulling	7.3	3.5	3.5
Total	9.8	6.3	5.5
Estimated percent success (areal) at removal of Eurasian watermilfoil from colonies where			
Eurasian watermilfoil dominates	95	90	95
Other species dominate	40	80	90
Estimated percent success (areal) at root removal	35	50	90
Total wet weight of Eurasian watermilfoil removed, g	7933	20,801	5992

LARGE-SCALE OPERATIONS MANAGEMENT TEST TO EVALUATE PREVENTION METHODOLOGY FOR CONTROL OF EURASIAN WATERMILFOIL IN WA HINGTON

Laboratory Evaluations of Eurasian Watermilfoil Fragment Viability

by

*Michael A. Perkins**

Introduction

Eurasian watermilfoil (*Myriophyllum spicatum* L.) is an exotic aquatic plant thought to have been introduced into North America sometime around the turn of the century. While difficulties exist concerning specific taxonomic interpretation, it is clearly evident that this plant, or a variety thereof, is now widely distributed throughout the United States and Canada. Where it does occur or become established, its prolific growth most often results in water use problems.

The situation in the Pacific Northwest is no different in this respect. While modes of introduction or specific environmental requirements have yet to be fully defined, nuisance growths of milfoil have been described in both British Columbia, Canada, and Washington State. It is apparent that the regional distribution of the plant is increasing and will most likely continue to do so. A large area of the Snake and Columbia River systems is potentially capable of sustaining milfoil growth; central and eastern Washington State are areas of particular critical concern. Milfoil infestations within the Okanogan River basin in British Columbia are thought to represent a major source for introduction into the Columbia River system (Figure 1).

Studies on the biology and reproductive characteristics of Eurasian watermilfoil suggest that, while viable seed production may be prolific and ensure the continuation of the species, asexual reproduction through axillary bud production and vegetative fragmentation (auto fragmentation) with subsequent fragment dispersal is a more dominant process and probably accounts for the rapid and widespread distribution of the plant (Patten 1956; Smith, Hall, and Stanley 1967; Grace and Wetzel 1978). The work of Wilson (1972) would suggest that milfoil fragments may be particularly suited for this role in that they tend to accumulate excess quantities of plant nutrients, which would favor their survival during the free-floating period when concentrations of nutrients in the aqueous medium may be limiting. Aside from auto

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fragmentation processes, a variety of aquatic activities may also lead to the production of fragments (e.g., boating, harvesting) that may serve as propagules for dispersal.

In consideration of the potential role of fragmentation as a dispersal mechanism, containment barriers have been employed within the

Figure 1. Washington State showing locations of river basins and lakes mentioned in the report. Sources of fragments utilized in the study were Lake Washington's Union Bay (UB) and the Okanogan River just below the outlet of Lake Osoyoos

Okanogan River basin in an attempt to retard the passive dispersal of fragments within specific lakes and/or into the State of Washington. An evaluation of the drift of milfoil fragments in the Okanogan River and the effectiveness of the barriers for containment is currently being conducted.* However, it seems likely that active processes involving transport mechanisms such as waterfowl or interlake boat traffic may constitute an equally important avenue for dispersal. A quarantine project conducted in British Columbia indicated that approximately 24 percent of the boats that left milfoil-infested water bodies did so with fragments attached to their equipment (Province of British Columbia 1978).

With either active or passive dispersal mechanisms, a central question that needs further evaluation concerns the viability of these fragments. While it has been reported that a single fragment can generate a prodigious number of new fragments in a years time (Coffey and McNabb 1974), the durability of these fragments appears to be generally assumed. The relationship between fragment viability and factors such as size, desiccation, or quality of receiving water has not been fully defined.

It would be intuitively reasonable to assume that a milfoil fragment could withstand desiccation for only a limited period of time before losing the ability to take root and grow. The importance of transfer mechanisms such as boat trailers might then relate to the period of time the trailer, boat, and any adhering fragments were out of the water.

The various fragmentation processes can be expected to lead to the production of fragments that vary in size. Smaller sized fragments may be more easily dispersed by waterfowl or might escape containment barriers such as those described above. The viability of small fragments would seem important in an assessment of the effectiveness of containment programs for controlling plant dispersal.

The question of water quality characteristics assumes considerable importance since they undoubtedly serve a basic regulatory function in regard to interlake transport. Eurasian watermilfoil is considered to be a calciphilous plant. The relationships between pH, alkalinity, calcium concentrations, and plant distribution have been indicated by Spence (1967); Hutchinson (1970); Van, Haller, and Bowes (1976); Grace and Wetzel (1978), and others. The extent to which plant populations become adapted to local water quality conditions must, to some degree, dictate the viability of fragments derived from that population for transport to other water systems of differing characteristics.

The work described herein was directed toward further elucidation of factors that may influence milfoil fragment viability. The ability

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* Personal communication, D. Thayer, Okanogan County Weed Control, Oroville, Washington.

of milfoil fragments to take root and grow was used as the measure of response; emphasis was placed upon evaluating the influence of drying and varying fragment length.

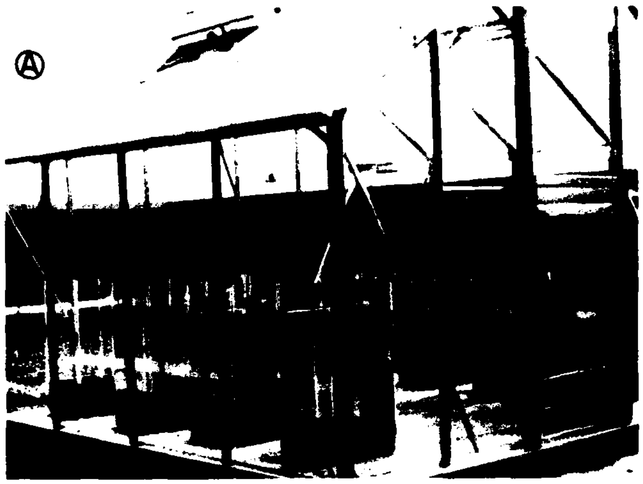
Methods and Materials

Plant material for testing was obtained from two areas within Washington State. Union Bay, a heavily infested embayment at the outlet of Lake Washington, was selected as the source of milfoil representative of plant growths within western Washington. The Okanogan River, just below the outlet Lake Osoyoos, served as the second source and was selected primarily because of the importance given to fragment drift from British Columbia (Figure 1). In both cases, whole plants were manually collected, washed free of adhering debris and periphyton, and transferred to the laboratory for processing.

The growth experiments were conducted in 30- by 30- by 60-cm (1- by 1- by 2-ft) chambers constructed of 0.6 cm (1/4 in.) clear plexiglass. Each chamber contained 15 cm (6 in.) of organic sediment obtained from milfoil beds within Union Bay. Coarse plant materials and other debris were removed from the sediments. To ensure uniformity, individual sediment samples were mixed prior to introduction to the chambers. The chambers were then filled to approximately 5 cm from the top (40 cm water column) with water collected from Union Bay and allowed to equilibrate in the dark for at least 7 days before plant materials were introduced. To compensate for evaporative losses, water levels were maintained at the 5-cm mark for the duration of the experiments. The plexiglass growth chambers were set up in a glass greenhouse in order to provide natural lighting (Figure 2a, b). No attempt was made to control water temperature variation. The experiments began on 17 August and were terminated on 3 October. Air temperature within the greenhouse was monitored daily with a maximum-minimum thermometer. Over the period of investigation the maximum averaged 35.2° $\pm$ 2.3°C and the minimum averaged 11.8° $\pm$ 1.2°C.

Processing of the plant materials entailed an initial separation and tap water washing of vegetative shoots. Ten-centimetre unbranched apical sections were then removed and transferred to buckets containing Union Bay water. For each treatment, 10 fragments were individaully drawn from each bucket. Treatments consisted of either air drying in the laboratory at 25°C for varying periods of time or subsectioning the 10-cm fragments into smaller lengths.

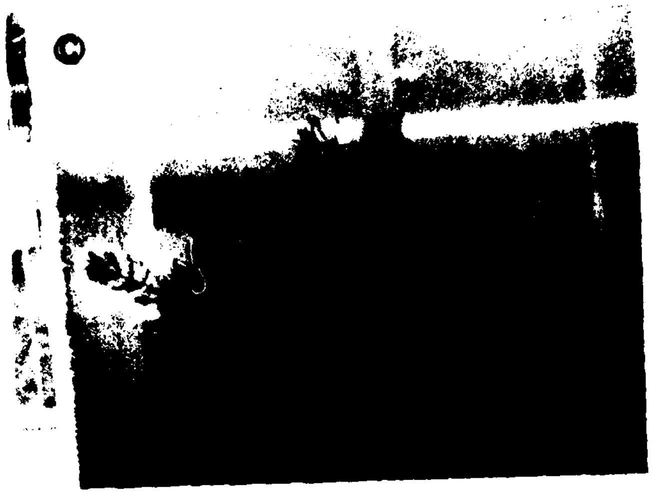
The fragment lengths used were 0.5, 1.0, 2.0, 5.0, and 10.0 cm. With the exception of the 0.5-cm fragments, only apical cuttings were tested. Both apical and intersegmental fragments were utilized for the 0.5-cm tests. After cutting to the required lengths, 10 fragments from Osoyoos and 10 fragments from Union Bay were immediately transferred to the growth chambers with the basal end being inserted into the substrate. The 0.5-cm fragments were allowed to float rather than being



a. Greenhouse

b. Growth chambers

Figure 2. Growth experiments (Continued)



c. 10-cm fragment after 14 days of growth

d. Growth chamber, 10-cm fragments after growing 14 days

Figure 2. (Concluded)

implanted. An additional 10 fragments from each size class were then taken for the determination of average dry weight and node count. Dry weights were determined after oven drying at 60°C for 24 hr.

Shoot growth and root development were used as the criteria for fragment viability. Evaluations were made after 14 and 28 days growth (Figure 2c, d) at which times the chambers were examined for percent survival. One half of the surviving plants were removed for determination of average shoot length and average shoot and root dry weight at 14 days and the remaining plants were removed at 28 days.

The drying experiments were all conducted with 10-cm apical fragments. The drying times for the initial experiment were 1, 2, 6, and 8 days (Figure 2e). Ten fragments from both Lake Osoyoos and Union Bay were selected for each drying time. Each fragment was blotted to remove excess moisture and the fresh weight was determined. The fragments were then placed in enamel pans and allowed to air dry (25°C) for the designated periods after which the fragments were reweighed. The fragments were then rewetted with Union Bay water and transferred to the growth chambers in the greenhouse. In a subsequent run of the drying experiments, new collections of Osoyoos and Union Bay plants were obtained. Ten-centimetre apical cuttings were again prepared as previously outlined, but the drying periods were shortened to 6, 12, 18, 24, and 48 hr. After drying, the fragments were rewetted and transferred to the growth chambers, but this time allowed to float in the chambers rather than being implanted in the sediment as had been done for the initial test. The 10-cm fragment length plantings served as controls for the drying experiments.

Results

The results of the fragment length experiments are summarized in Table 1. Data collected for the initial dry weights of the various fragment lengths were lost and the values appearing in the tables were estimated from a separately derived regression of dry weight against fragment length. The linear transformation of the regression was:

$$\text{Ln dry wt} = \text{Ln } 0.0108 + 0.1777 \text{ Length}, \; r^2 = 0.645, \; n = 53 \qquad (1)$$

Most of the Union Bay fragments showed a good growth response expressed either in terms of increases in shoot length or dry weight. While plant growth within the size classes was somewhat variable, a consistent pattern was the tendency for relative increases (percent increase over initial condition) to be greater for the smaller sized fragments (1 and 2 cm) while the absolute values were greater for the larger sized fragments (5 and 10 cm).

Table 1

Summary of Milfoil Fragment Length Experiments

	Union Bay			
Initial				
Length, cm	1	2	5	10
No. nodes	3	4	8	13
Total dry wt, mg*	12	15	26	64
14 days growth				
Shoot length, cm	2.5 ± 0.4	4.2 ± 0.6	9.3 ± 4.1	13.2 ± 1.2
Shoot dry wt, %	94.2	93.3	83.0	91.0
Root dry wt, %	5.8	6.7	17.0	9.0
Avg dry wt, mg	28.0 ± 1.3	40.2 ± 7.0	72.9 ± 18.7	165.9 ± 18.4
Percent survival	90	90	100	100
28 days growth				
Shoot length, cm	8.5 ± 2.1	14.7 ± 2.0	24.3 ± 3.5	20.3 ± 3.4
Shoot dry wt, %	81.9	82.8	85.4	83.6
Root dry wt, %	18.1	17.2	14.6	16.4
Avg dry wt, mg	102.0 ± 32.5	161.3 ± 46.4	228.3 ± 28.7	331.0 ± 91.0
Percent survival	90	90	100	100
	Lake Osoyoos			
Initial				
Length, cm	1	2	5	10
No. nodes	3	4	6	12
Total dry wt, mg*	12	15	26	64
14 days growth				
Shoot length, cm	3.3 ± 1.8	6.9 ± 1.9	6.4 ± 0.7	9.2 ± 2.3
Shoot dry wt, %	86.5	84.9	75.1	82.2
Root dry wt, %	13.5	15.1	24.9	17.8
Avg dry wt, mg	10.6 ± 2.6	30.6 ± 10.2	37.8 ± 13.9	88.8 ± 70.5
Percent survival	40	50	60	50
28 days growth				
Shoot length, cm	11.1 ± 2.0	19.0 ± 0.2	20.1 ± 2.4	22.6
Shoot dry wt, %	72.7	81.8	86.2	83.8
Root dry wt, %	27.3	18.2	13.8	16.2
Avg dry wt, mg	117.4 ± 1.0	137.2 ± 7.5	200.8 ± 18.7	465.5
Percent survival	40	40	50	30

Note: Intervals for the mean are plus or minus 1 standard error.
* Values estimated from regression of length versus dry weight.

Based upon percent survival, the growth of the Osoyoos fragments was poor. Two to three days after introduction into the growth chamber these fragments began to discolor. By 2 weeks it was apparent that less than half of the fragments would survive. For those fragments that did survive the transfer to Union Bay water and sediment, the growth response was comparable to that observed for the Union Bay fragments. The same tendency for relative increases to be greater for the smaller fragment sizes was observed.

After 28 days in the growth chambers, the mean growth of surviving fragments (including branches) expressed as centimetres of shoot length increase was 7.5, 12.7, 19.3, and 10.3, respectively, for the 1-, 2-, 5-, and 10-cm Union Bay fragments and 10.1, 17.0, 15.1, and 12.6, respectively, for the 1-, 2-, 5-, and 10-cm Osoyoos fragments.

The average dry weights for the various fragment sizes (shoot and root) at 14 and 28 days are presented graphically in Figure 3. A lag in the growth response of the Osoyoos fragments is evident, but by 28 days the average dry weights were comparable. The increasing slopes tend to suggest that the larger fragment sizes grew more rapidly. Growth rates, expressed as the average 28-day accrual of total plant dry weight, were similar for both Union Bay and Osoyoos fragment sizes. These rates, as milligrams dry weight per day, were 3.21, 5.21, 7.21, and 9.54 for the 1-, 2-, 5-, and 10-cm Union Bay fragments, respectively, and 3.75, 4.36, 6.25, and 14.34 for the 1-, 2-, 5-, and 10-cm Osoyoos fragments, respectively. These rates are shown in Figure 4 as a function of initial fragment length. The comparability and tendency for the average rates to generalize to a single curve are evident. The condition of the 10-cm fragment growth chambers is shown in Figure 2c and 2d.

There were no consistent differences in the extent of root development for the various fragment sizes. After 14 days, mean root dry weight expressed as a percent of total plant dry weight was 9.6 ± 7.1 for the Union Bay fragments and 17.8 ± 7.0 for the surviving Osoyoos fragments. Root development after 28 days growth amounted to 16.6 ± 2.1 percent for the Union Bay fragments and 18.9 ± 8.2 percent for the Osoyoos fragments. The tendency for a greater proportion of plant growth to be diverted to early root development in the Osoyoos fragments is evident but not significant based primarily upon the small numbers of surviving replicates.

While growth response based upon mean increases in length or plant dry weight would suggest a close similarity between Union Bay and Osoyoos fragments, a more accurate representation of the results of the length experiments would reflect the percent mortality observed with the Osoyoos fragments. Total plant biomass (grams dry weight) accumulating within the various chambers was computed on the basis of average dry weight and percent survival. The results are presented in Figure 5. After 14 days growth, plant biomass for all fragment sizes of the Osoyoos plants averaged only 29 percent of that for the Union Bay fragments. By 28 days, plant biomass for the Osoyoos fragments had

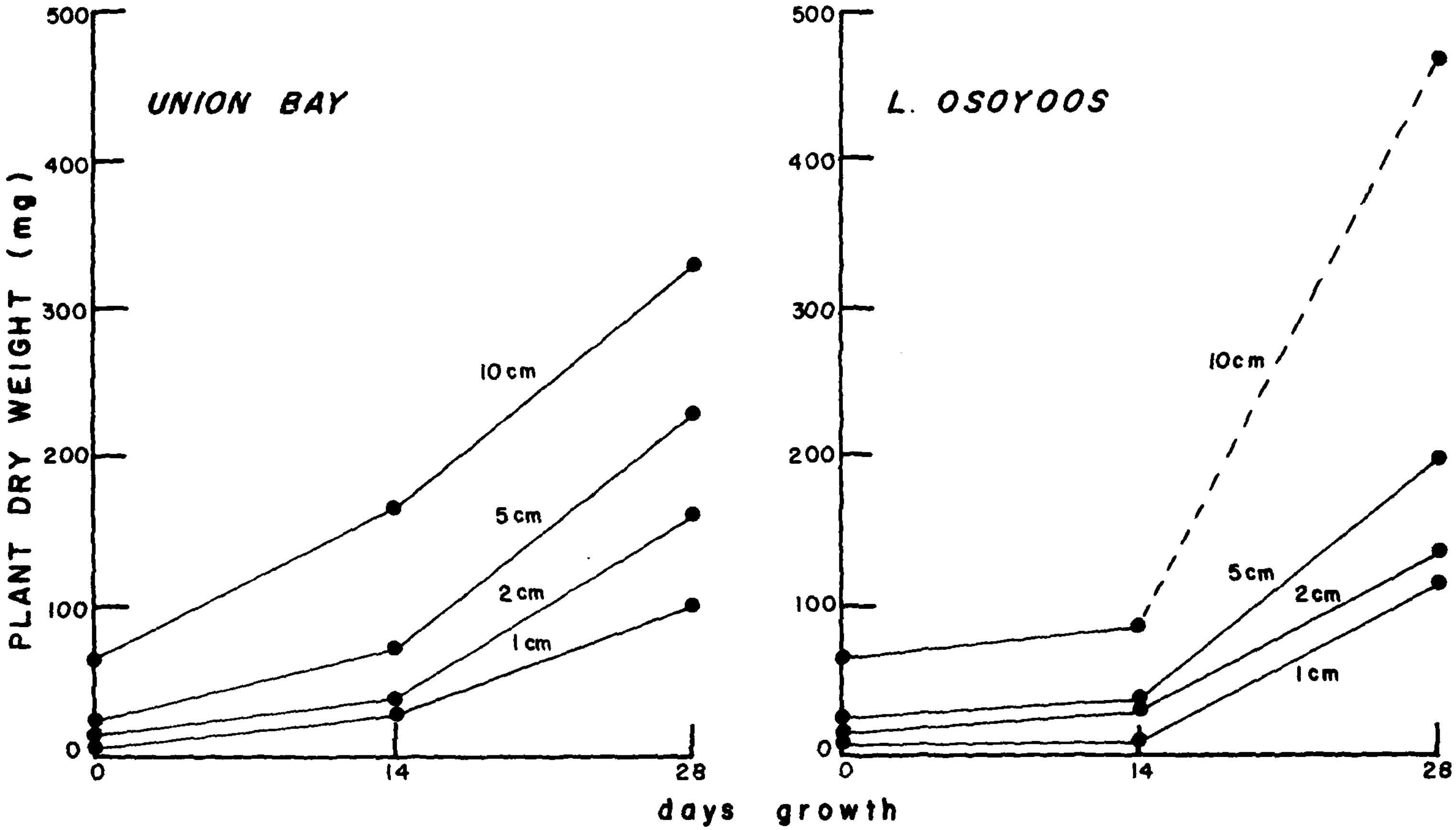


Figure 3. Average increases in plant dry weight (shoot + root) for various fragment lengths over a 28-day growing period

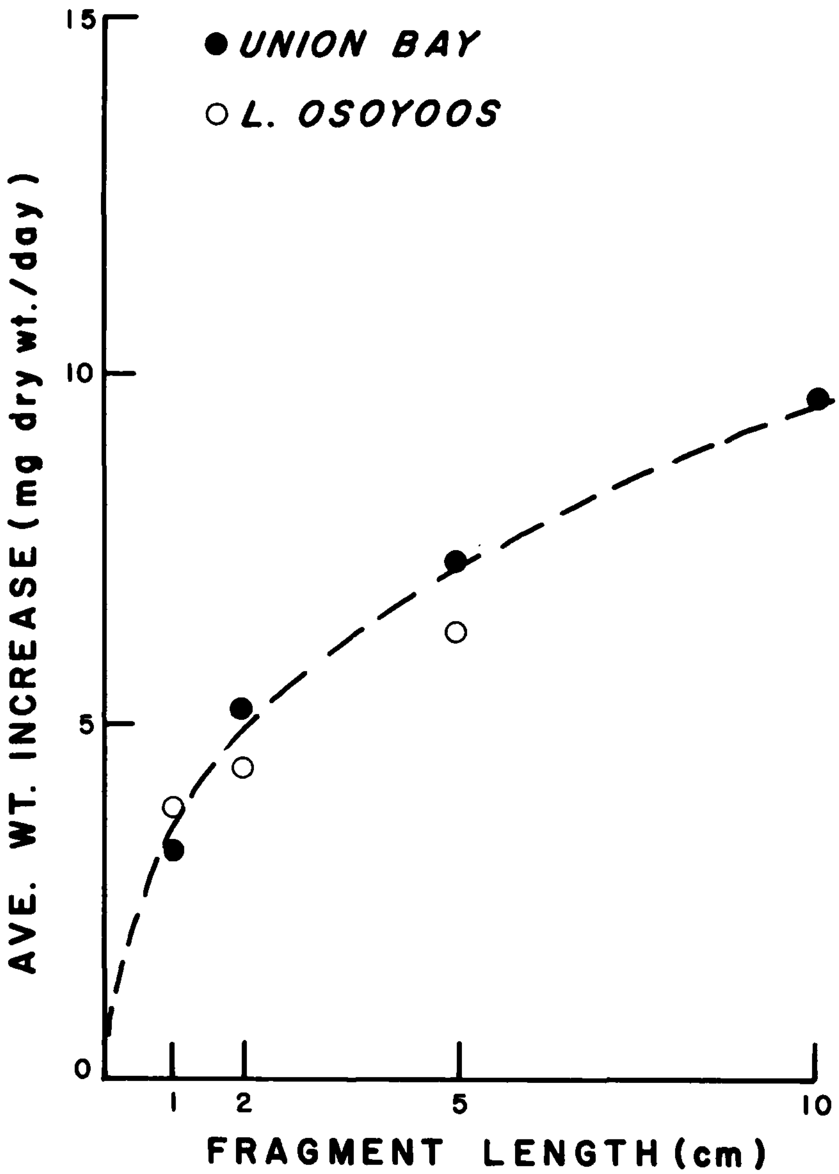


Figure 4. Growth rate expressed as average daily accrual of plant dry weight as a function of initial fragment length

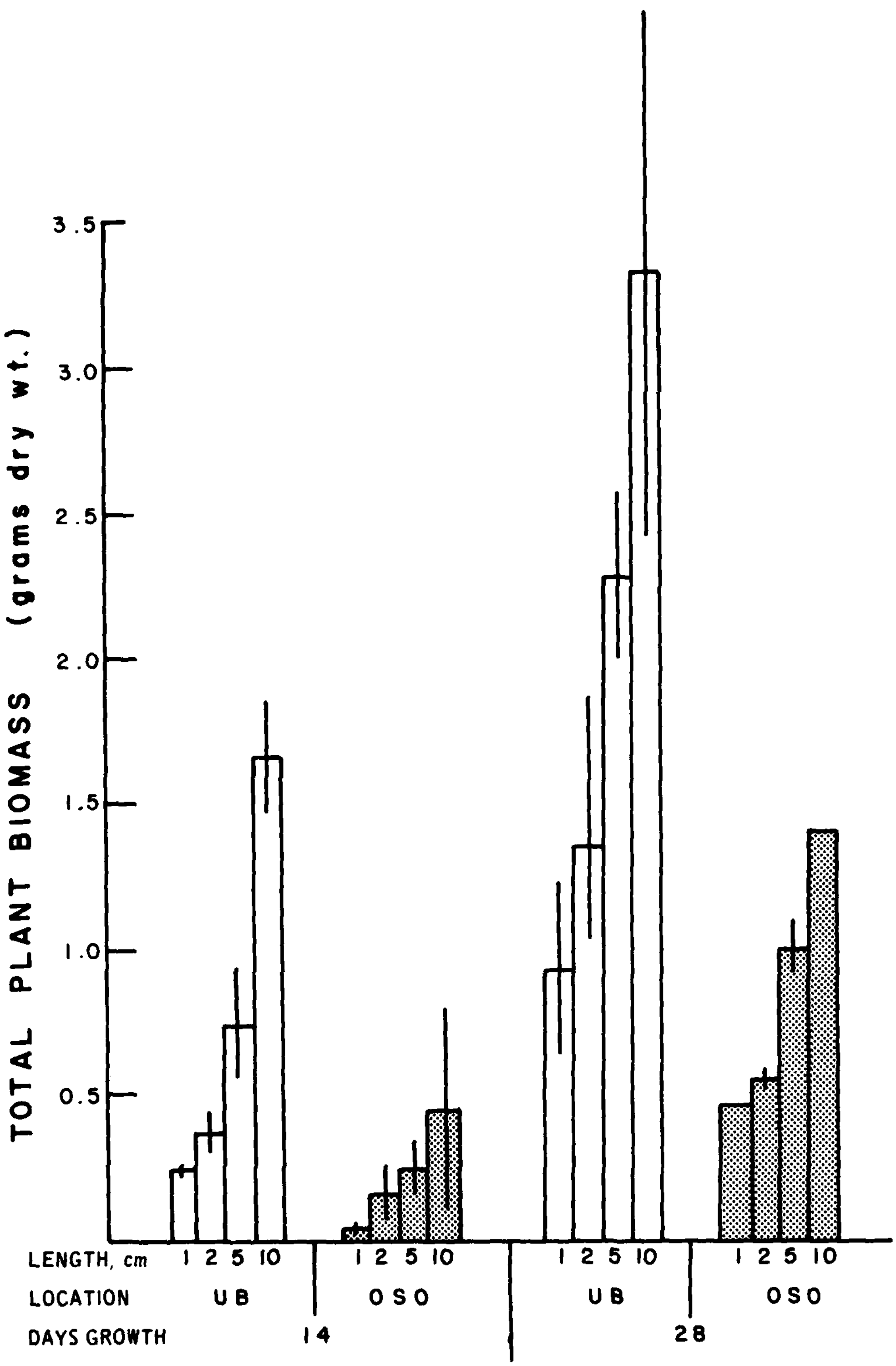


Figure 5. Total plant biomass accumulation (grams dry weight) computed on basis of mean dry weight per fragment and percent survival

increased but still averaged only 44 percent of that attained by the Union Bay fragments.

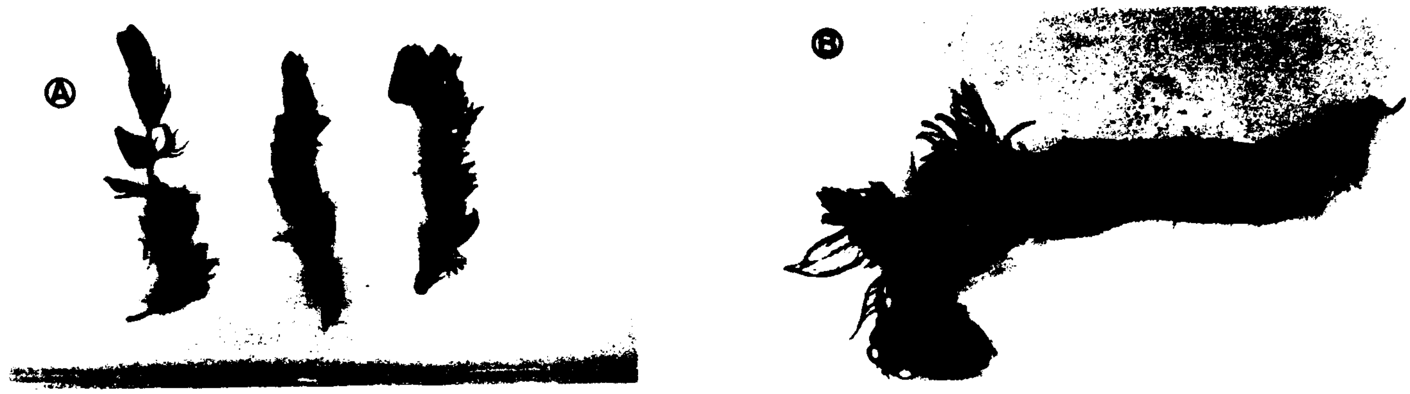
The 0.5-cm fragments were derived from both apical and intersegmental cuttings, five of each were taken from both Osoyoos and Union Bay material. Each fragment had a single whorl of leaves. Nine of the Union Bay fragments, five intersegmental and four apical, showed a positive growth response after 14 days. Five of the Osoyoos fragments, two intersegmental and three apical, showed shoot and root development over the same period. Growth of the intersegmental fragments consisted of new shoot and adventitious root formation originating from the leaf axials. Average new shoot length for the Union Bay intersegmental fragments was 2.8 ± 1.0 cm with all fragments developing either one or two roots. Only two of the Osoyoos intersegmental fragments showed signs of root initiation and only one of these had new shoot development (2.7 cm).

Growth of the 0.5-cm apical fragments consisted of shoot elongation and expansion from the terminal bud. The four Union Bay fragments had an average shoot growth of 2.8 ± 1.1 cm and each formed one adventitious root. The three Osoyoos fragments had an average shoot length of 3.2 ± 2.8 cm with one, two, and three adventitious roots forming on the individual fragments.

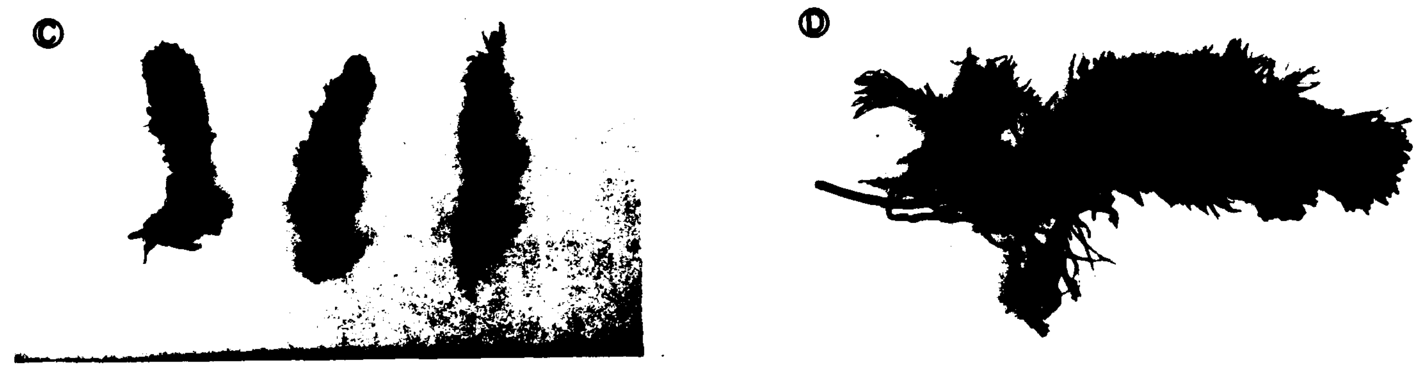
The mean fresh weight of material at the initiation of the fragment drying experiments was 0.629 ± 0.11 g for the 10 Union Bay fragments and 0.589 ± 0.13 g for the 10 Osoyoos fragments. Weight loss for all of the dried fragments was fairly constant regardless of drying time and amounted to approximately 84 percent of the fresh weight. The Osoyoos fragments were noticeably encrusted with calcium carbonate (Figure 6a), while the Union Bay plants showed only slight encrustation (Figure 6b). Upon rewetting the fragments prior to planting in the growth chambers, all appeared green and healthy (Figure 7a, b).

After 2 days in the growth chambers, the plants began to discolor, turning from green to brown. After 1 week, the fragments from both Union Bay and Osoyoos appeared sickly and were heavily epiphytized. Plants removed at this time showed no visible sign of shoot growth, new shoot formation, or root development. At the end of 14 days the fragments for all drying periods were dead and partially decomposed (Figure 8). This condition may be compared to the 10-cm fragment length tests that served as the controls for the drying experiments. The Union Bay fragments showed an average increase in dry weight of 160 percent, 100 percent survival, and root development averaging 9.5 percent of the total plant dry weight. The Osoyoos 10-cm fragments showed 50 percent survival with an average increase in dry weight of 38.7 percent and root development averaging 17.8 percent of the total plant dry weight (Figure 2c, d). Observations on the dried plants showed no sign of either root or shoot initiation at 14 days and the experiment was terminated.

To further test the effects of fragment drying, new collections of Osoyoos and Union Bay plants were obtained and 10-cm apical cuttings



a. 10-cm Osoyoos fragments dried 48 hr



b. 10-cm Union Bay fragments dried 48 hr

Figure 6. Fragment encrustation

a. Osoyoos

b. Union Bay

Figure 7. Fragments dried 48 hr and rewetted prior to planting

Figure 8. Fragments dried 2 days prior to planting. Fragments shown here 14 days after planting

were prepared. Drying times were shortened to 6, 12, 18, 24, and 48 hr. After drying, the fragments (10 each treatment) were rewetted with Union Bay water, transferred to the growth chambers, and allowed to float rather than being implanted in the sediment.

Weight loss with drying at 25°C proceeded very rapidly and leveled off after 12 hr at $86^{\circ} \pm 2.8$ percent of the fresh weight (Table 2, Figure 9). Weight loss after 6 hr drying averaged 77 percent of the fresh weight.

The fragments again became discolored soon after placement in the chambers and by 5 days most fragments appeared necrotic. There were no apparent differences in response with either the Union Bay or Osoyoos fragments; the 12-, 24-, and 48-hr dried fragments showed no evidence of viable plant growth. Some indication of new shoot initiation from leaf axials was observed in eight of the 6-hr dried fragments (four Union Bay, four Osoyoos) and two of the 18-hr dried fragments (both Union Bay).

After 14 days in the growth chambers, the 12-, 24-, and 18-hr dried fragments had all sunk to the sediments and were partially decomposed. There was no evidence of root or shoot initiation on any of these fragments. Three of the 20 fragments that had been dried for 18 hr (two Union Bay, one Osoyoos) showed limited signs of auxiliary shoot formation but no significant growth. Thirteen of the fragments that had been dried for 6 hr contained new auxiliary shoots and some adventitious root formation. New shoots averaged three per fragment and ranged in length from 0.5 to 2.0 cm.

Table 2

Eurasian Watermilfoil Fragment Drying Summary

Drying Time hr	Initial Weight, g	Final Weight, g	Average Weight Loss, g	% Survival After 14 days
		Union Bay		
6	0.6826 ± 0.0545	0.1796 ± 0.0205	0.5030 ± 0.0385	70
12	0.7475 ± 0.0818	0.1223 ± 0.0168	0.6261 ± 0.0658	0
18	0.9422 ± 0.1019	0.1512 ± 0.0172	0.7910 ± 0.0878	20
24	0.8924 ± 0.1215	0.1490 ± 0.0102	0.7434 ± 0.1137	0
48	0.8002 ± 0.1003	0.1373 ± 0.0142	0.6629 ± 0.0893	0
		Lake Osoyoos		
6	0.8438 ± 0.0913	0.1697 ± 0.0300	0.6742 ± 0.0655	60
12	0.7169 ± 0.0669	0.0832 ± 0.0112	0.6251 ± 0.0638	0
18	0.7715 ± 0.0756	0.0823 ± 0.0075	0.6892 ± 0.0690	10
24	0.9264 ± 0.1256	0.0906 ± 0.0089	0.8359 ± 0.1185	0
48	1.0862 ± 0.1592	0.1159 ± 0.0160	0.9703 ± 0.1435	0

Note: 10-cm apical cuttings air dried at 25°C for variable time periods. Values are means ± 1 std error, n = 10 for all times.

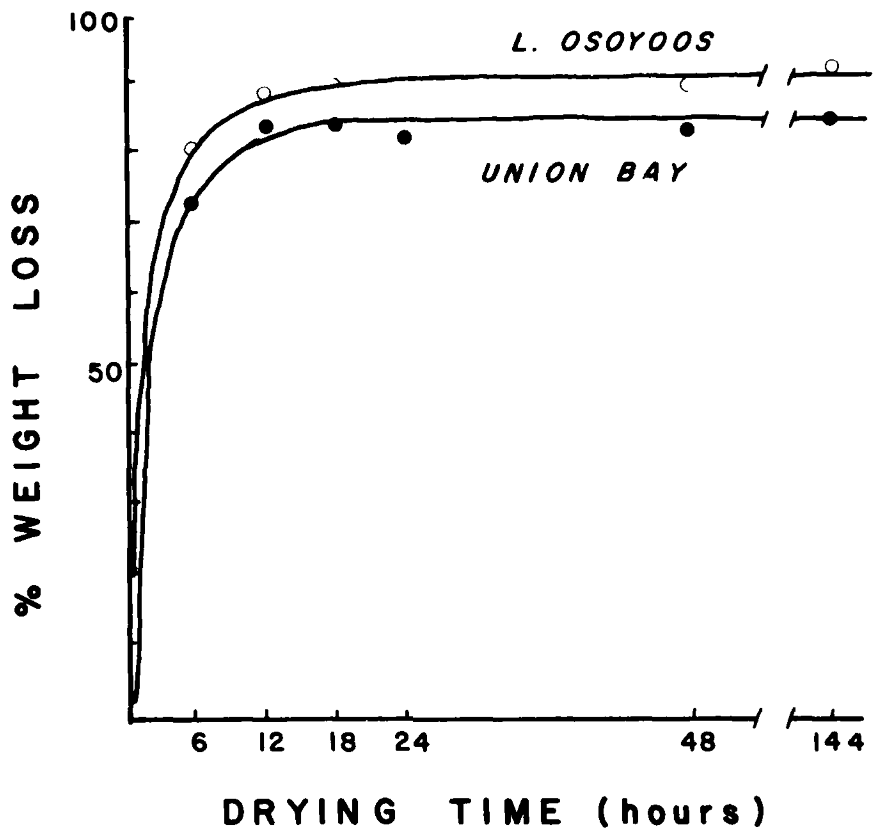


Figure 9. Percent weight loss as a function of drying time at 25°C for 10-cm apical fragments of Eurasian watermilfoil

Discussion

Asexual reproduction through vegetative fragmentation has been implicated as a major process accounting for the successful spread of Eurasian watermilfoil (Patten 1956; Smith, Hall, and Stanley 1967; Coffey and McNabb 1974). With some reservation, the results of the work reported herein support that contention. Fragment survival and viability, regardless of length or stem origin, are high within a body of water having comparable characteristics. Fragments containing but a single whorl of leaves can initiate new shoot and root formation that, once settled in a suitable substrate, would lead to new plant populations.

Perhaps the most striking result of the length experiments was the failure to obtain good growth with the Okanogan milfoil. Disregarding initial fragment lengths, of the 40 plantings only 20 survived to 14 days. Counting plants removed at 14 days as survivals, only 16 plants would have survived 28 days growth for a 60 percent mortality. This is in contrast to the Union Bay fragments that had only a 5 percent mortality after 28 days growth.

The differences may be attributable to water quality characteristics of the two sources of plant material and the fact that only Union Bay water and sediment was used as the growth medium. A summary of selected water quality characteristics for the two sources is presented below:

Source	Total Alkalinity $mgCaCO_3/\ell$	pH	Na mg/ℓ	K mg/ℓ	Ca mg/ℓ	Mg mg/ℓ	Hardness (Ca, Mg) $mgCaCO_3/\ell$
Osoyoos*	97-125	8-8.9	9.9	2.3	34.2	8.7	121
Union Bay**	33-40	6-8	3.5	1.4	10	5	46

* Personal communication, Newroth and Bryan, British Columbia Ministry of Environment.

** Data from Perkins, Boston, and Curren (1979).

It would seem likely that plants adapted to the hard water condition of the Okanogan River basin would be stressed by the transfer to the relatively soft water condition of Union Bay. This may account for the observed mortality of Osoyoos fragments. It is interesting to note that the Osoyoos condition would correspond to pH and calcium envelopes developed by Hutchinson (1970) for central Sweden while the Union Bay condition would correspond to northern Swedish lakes. The observation that surviving Osoyoos fragments gave comparable average growth responses to the Union Bay fragments suggests that, while the transition may be difficult, it can be successful. Giesy and Tessier (1979) reported successful *M. spicatum* transplants under even more extreme conditions of alkalinity, hardness, and calcium concentrations although their plants were already adapted to a low alkalinity, relatively soft water condition.

The question of water quality characteristics related to plant dispersal undoubtedly has significance in regard to initial fragment survival. However, the argument may be moot in the sense that there need be only one surviving fragment to ensure future generations.

The results of the drying experiments have obvious implications in regard to interlake transport of fragments by mechanisms such as boat trailers. Under the somewhat moderate conditions of drying (25°C) utilized, the fragments showed a rapid weight loss (Figure 9) and almost complete mortality after 12 hr of drying. Clearly, the importance of interlake transport by boat trailers must be viewed with some doubt. While initial quarantine studies in British Columbia suggested a moderate transport of milfoil fragments on boats and trailers (24 percent of boats examined) leaving milfoil-infested lakes, continued evaluations indicate that only a very small fraction of boats still contained

fragments further on down the road (88 boats out of 18,000 examined).* Coupled with the observations on drying, the effectiveness of this particular transport mechanism is questionable.

* Personal communication, Peter R. Newroth, British Columbia Ministry of Environment.

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LARGE-SCALE OPERATIONS MANAGEMENT TEST USING THE WHITE AMUR AT LAKE CONWAY, FLORIDA

An Overview

by

Eugene G. Buglewicz*

The Large-Scale Operations Management Test (LSOMT) using the white amur fish was initiated in February 1975 at a meeting held at the U. S. Army Engineer Waterways Experiment Station (WES) and attended by Corps of Engineer representatives from the South Atlantic Division; Jacksonville District; Office, Chief of Engineers; U. S. Fish and Wildlife Service; U. S. Department of Agriculture; and other agencies.

One of the purposes of the meeting was to determine if research had matured to the point that it could be tested on a large scale. Results of small-scale studies had shown that the white amur had the ability to control the aquatic plant hydrilla. It was concluded that the white amur had the potential for use as a macrophyte control agent in a large-scale test, and that the State of Florida with its aquatic plant problems, specifically hydrilla, may be receptive to using the fish applying the concept of an LSOMT.

The large-scale test concept was presented to the State of Florida as a way of answering questions concerning the effect of the white amur on hydrilla; the effect of the white amur on nontarget components of the ecosystem; the effect of the white amur on the ecology of the lake; and the definition of the operational requirements for using the white amur as an aquatic plant management tool.

After much deliberation and searching, Lake Conway, near Orlando, Florida, was selected as the LSOMT site. Lake Conway is a series of five interconnected pools with a surface area of approximately 7.5 km^2. Lake Conway is an urban lake with a considerable amount of shoreline supporting permanent homesites.

Study milestones initially set for the LSOMT included a 1-year period of baseline data collection (prestocking studies) and approximately 3 years of poststocking monitoring work. By September 1976, contracts to perform the baseline studies had been awarded and data collection had commenced with the exception of the herpetofauna work which commenced during 1977.

The Florida Game and Freshwater Fish Commission was responsible

* U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

for fish, mammal, and aquatic bird inventories and data collection; the Department of Natural Resources, the aquatic macrophyte populations; Orange County Pollution Control Authority, the characterization of water and sediment quality; University of Florida, zooplankton, phytoplankton, and benthic invertebrate populations as well as development of a general ecosystem response model; and, by the summer of 1977, the University of South Florida, herpetofauna characterization in Lake Conway.

Prior to stocking white amur, however, two considerations had to be addressed. The first was the escapement and possible reproduction of the fish outside the immediate study area. The U. S. Fish and Wildlife Service, under contract with the Corps of Engineers, had previously perfected a technique for producing an all-female (monosex) white amur population. These fish were not sterile; however, the chances of producing a male in a stocked population were considered very small. To prevent escape of the stocked population into an adjacent watershed, physical barriers were constructed at inflows and outflows to Lake Conway. Thus, using a monosex fish population and lowering the chance for escape from the test site, the probability of reproduction and/or escapement was considerably diminished.

The second consideration had to do with the numbers of white amur to be stocked to attain control of the aquatic plant population. A stocking rate model was developed at WES that described basic white amur-hydrilla interactions. The model used the then current literature values and expert opinion as to the growth, consumption, and predation of white amur, and growth rates of hydrilla as a function of total plant biomass.

As a result of the input from the prestocking studies and the running of the stocking rate model, an average of four fish per acre was stocked in Lake Conway in September 1977. With the stocking of the white amur, the study entered the poststocking phase of study with all contractors continuing to collect data on Lake Conway.

As the contractors' studies progressed into the poststocking phase, additional research needs were identified. These needs are discussed in the following paragraphs.

During discussions with the contractors over the course of the study period, general comments concerning loss of sampling sites became commonplace, reaching a crescendo during 1978. For instance, in a period of 2 weeks an established sampling site would be replaced by a graded sand beach, complete with sod lawn, swimming pool, and two-story house with boat dock. Since the white amur may eliminate littoral zone habitat, change water quality, cause fish populations to change, or cause other pertubations, it was obvious that loss or gain of components of the Lake Conway system would have to be quantified and apportioned between the white amur and other causes. As a result, this past summer, Randall Williams, WES, and William Brown, Central Florida University, initiated and completed a Human Factors Study in the Lake Conway area.

The stocking rate model developed for the Lake Conway study has shown its utility in providing an operational tool for the introduction of the white amur into an aquatic system. However, the model does have limits in that it can only handle one cohort of fish at a time. The need for multiple fish cohorts for aquatic plant management on a long-term scale is readily apparent; as the initial fish stock is removed for whatever reason (disease, predation, unexplained loss), thereby decreasing plant consumption rates, the possibility of regrowth of the target plant to nuisance proportions may occur. Second, the amount of information generated on both the white amur and hydrilla has increased considerably since 1975. This past year, the original model was evaluated in the light of this new information and additional requirements placed on the model. Hal Schramm, WES, conceived a second generation model taking into account the forcing functions included in the first generation model, but also including growth rate of hydrilla as related to season, photoperiod, density of plants, and cropping rate of the white amur. The white amur consumption rate, likewise, is calculated as a function of temperature, weight of the white amur, and season of the year. The status of this model is that it is currently on our computer and performed its first successful run on 15 November. The second generation model will be summarized in document form during January with recommendations for continued development.

The last major change to the study plan occurred this past fiscal year with the initiation of radiotracking the white amur and selected herpetological species. This particular project has involved the expertise of Malcolm Keown, physicist at WES, and Larry Nall and Jeff Schardt, Florida Department of Natural Resources, and Steve Godley, University of South Florida.

Intensive field data collection will cease in September 1980. We anticipate that some reduced level of fieldwork will continue at Lake Conway. We should assure ourselves that we have achieved control of the nuisance aquatic plant problem in Lake Conway; if we have not achieved control, we should determine to what extent we have eliminated or changed the populations of aquatic plants and be convinced that the changes in the other components of the Lake Conway system can be identified or anticipated. If we can accomplish these goals, we have conducted a successful large-scale operations management test.

LARGE-SCALE OPERATIONS MANAGEMENT TEST USING THE WHITE AMUR AT LAKE CONWAY, FLORIDA

Aquatic Macrophytes

by

Larry E. Nall* and Jeffrey D. Schardt*

Introduction

The Florida Department of Natural Resources under contract to WES has been conducting aquatic plant studies in Lake Conway since October 1976. As of 31 September 1979, 36 months of continuous data have been collected from the lake. The purpose of this report is to give interested parties a brief update of results at the conclusion of the third study year. It is impossible to give a complete presentation of results in the space allotted; therefore, the results presented herein are brief illustrations of the major trends presently occurring in Lake Conway. Preparation of a detailed report covering results through the third study year is in progress.

Methodology

Two major types of vegetation studies are employed in Lake Conway. The first type uses a hydraulic plant biomass sampling device which is lowered from a 24-ft pontoon boat (Figure 1). The boat and sampling device were designed specifically for use in Lake Conway. The device takes a measured sample at 100-m intervals along 18 transects whose locations are shown in Figure 2. Transect samples yield biomass and frequency of occurrence data.

The other major type of sampling is performed by a scuba diver. Sixteen 1.0-ha underwater study plots are located in areas of special interest (Figure 3). A diagram of an underwater plot is shown in Figure 4. The diver surveys the area to determine the percent frequency of occurrence, measures plant height at fixed points, and uses a 0.25-m^2 quadrant to collect plants from which stem density, wet weight, and plant height are recorded.

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* Florida Department of Natural Resources, Bureau of Aquatic Plant Research and Control, Tallahassee, Florida.

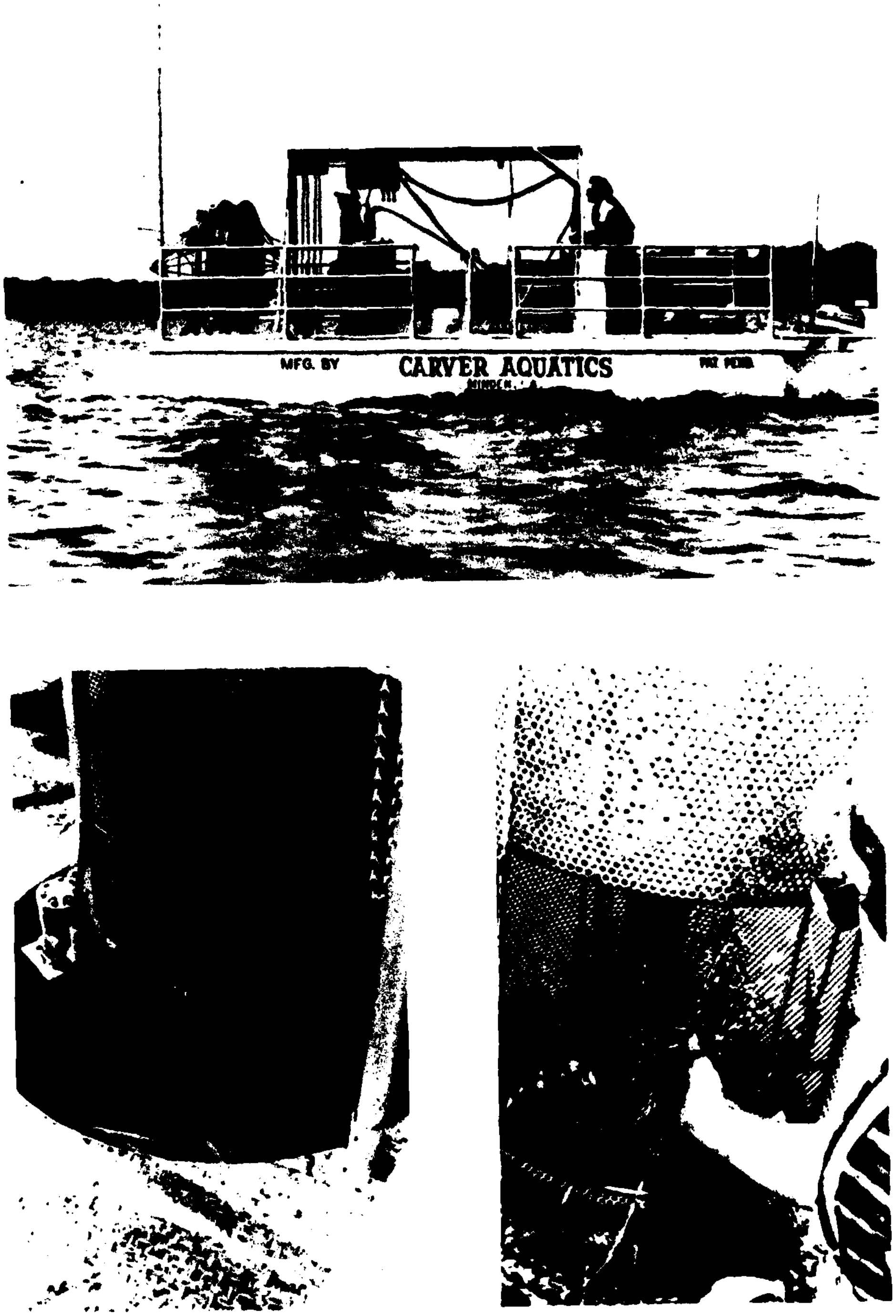

Figure 1. Lake Conway aquatic plant sampling device

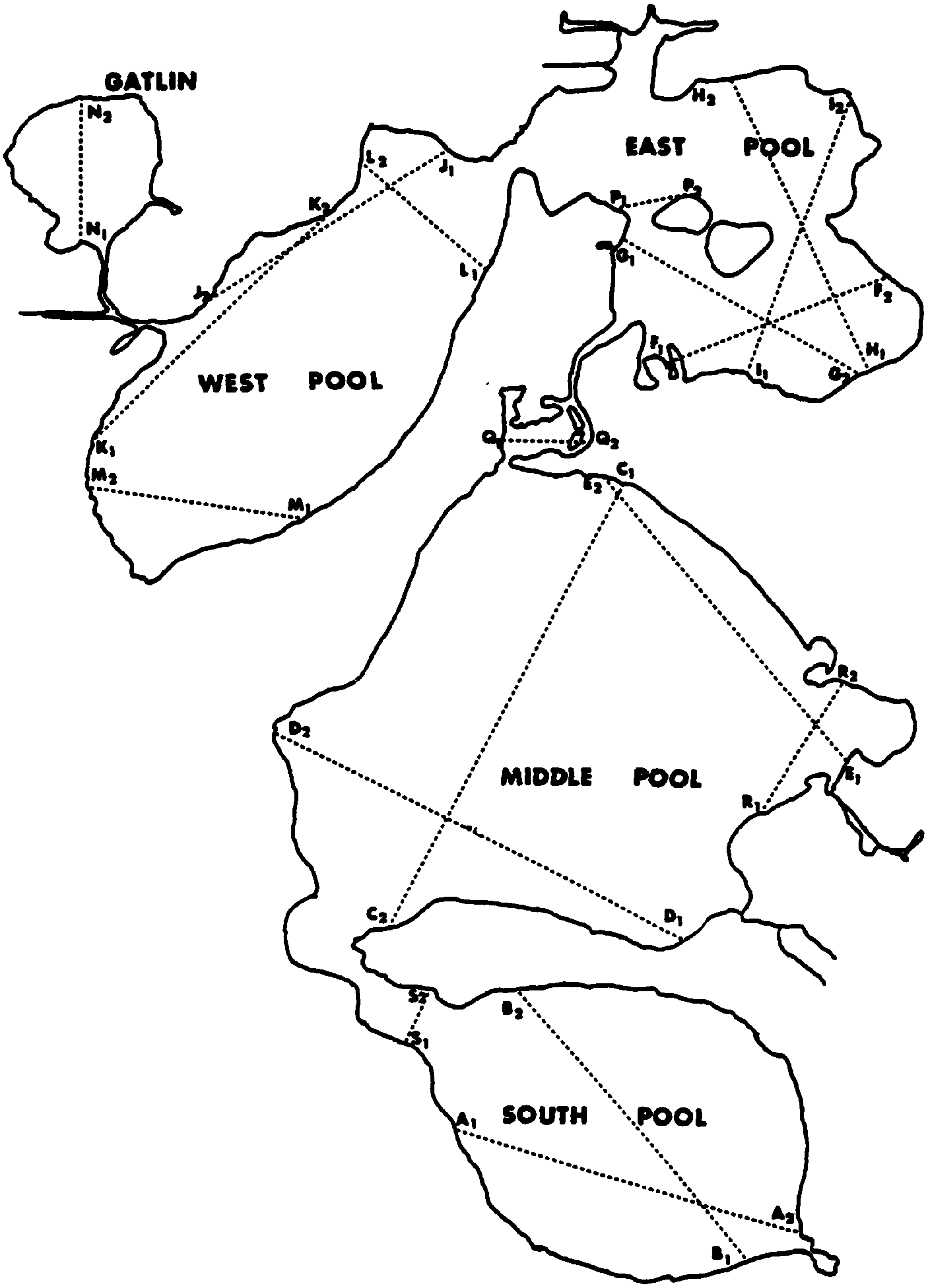

Figure 2. Lake Conway transect locations

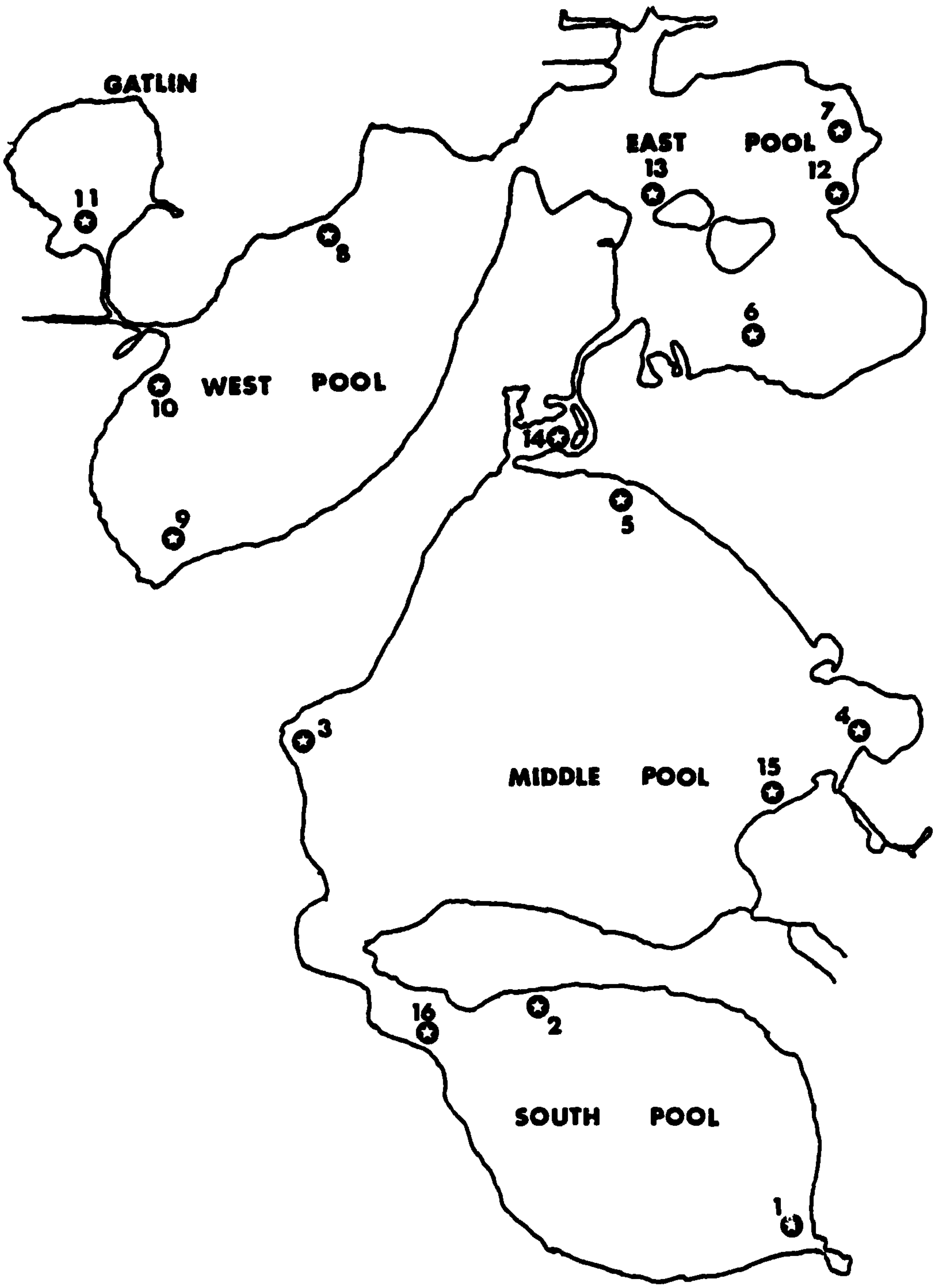

Figure 3. Lake Conway underwater plot locations

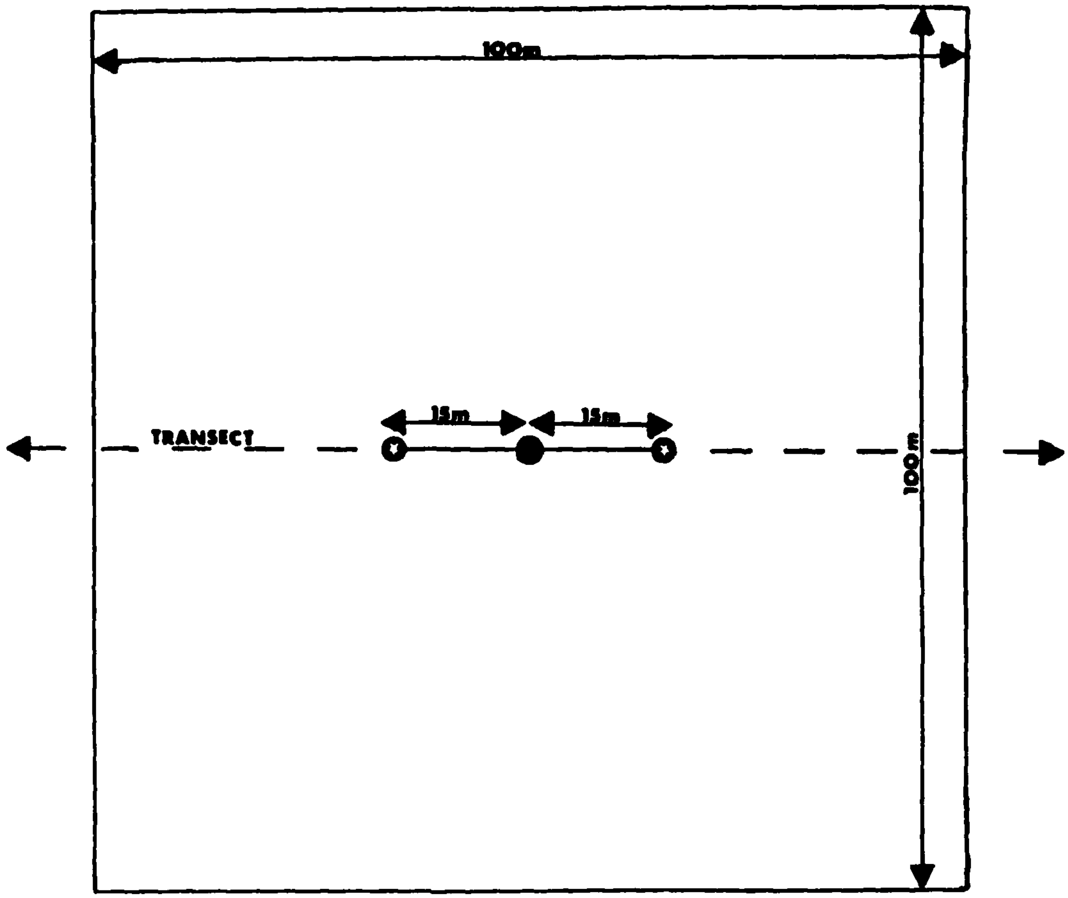

Figure 4. Diagram of underwater plot layout

The first annual report* contains greater detail on these sampling techniques and others in use in the study.

Results

Feeding preference

Table 1 presents a list of aquatic plant species in approximate

* Nall, L. E., and Schardt, J. D. 1978. "Large-Scale Operations Management Test of the Use of the White Amur for Control of Problem Aquatic Plants; Report I: Baseline Studies; Volume I: The Aquatic Macrophytes of Lake Conway, Florida." Technical Report A-78-2, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

Table 1

Approximate Feeding Preferences of the White Amur*,**

Greatly prefers:
* *Nitella* and *Chara* spp.
* *Hydrilla verticillata*
Najas spp.
* *Potamogeton* spp.
Duckweeds *(Lemna, Spirodella, Wolffia, Wolffiella, Azolla)*
Ceratophyllum demersum
Eleocharis acicularis
Elodea canadensis
Pithophora sp.
Will control but does not prefer:
Myriophyllum spp.
Bacopa spp.
Egeria densa
Nymphaea spp.
Polygonum spp.
Spirogyra sp.
Utricularia spp.
Cabomba spp.
Fuirena scirpoides
Brasenia schreberi
Hydrocotyle spp.
Will not control effectively:
* *Vallisneria* spp.
Typha spp.
Myriophyllum brasiliense
Phragmites spp.
Carex spp.
Scirpus spp.
Eichhornia crassipes
Alternanthera philoxeroides
Pistia stratiotes
Nymphoides spp.
Nuphar macrophyllum

* Only these species common to Florida are listed.

** Compiled from the literature. See Nall and Schardt (1978) for citations.

order of preference by the white amur. The positions of the four major species present in Lake Conway, *Hydrilla verticillata, Potamogeton illinoensis, Nitella megacarpa* and *Vallisneria americana,* are indicated by stars. Note that *Hydrilla, Potamogeton,* and *Nitella* are highly preferred but *Vallisneria* is not controlled effectively. It was believed strongly that *Vallisneria* would not be affected or would benefit by the amur's presence, but the order in which the three preferred species would be controlled, if at all, could not be confidently predicted because of their closeness on the list. The results that follow will show a definite preference.

Transects

Important effects detected by transect sampling are shown in Figures 5-11. Figures 5 and 6 show the changes for *Hydrilla* in the South and West Pools, respectively, which had the most significant *Hydrilla* populations. Percent occurrence of *Hydrilla* was found to be rising and reached a maximum coverage of about 70 percent in South Pool and about 55 percent in West Pool. Both distribution maximums occurred at about month 20 (May 1978). Afterwards, the coverage in both pools declined steadily until occurrence was negligible by month 36 (September 1979). Biomass also exhibited similar trends. The standing crops were low when first encountered. The biomass increased steadily until near the end of the second study year after which it declined to trace levels before the end of the third year. Distinct seasonal trends are evident in the *Hydrilla* biomass for both pools, but are most obvious in West Pool. Populations began increasing during the spring and maximums occurred during late summer. The population began to decline steeply in early fall.

Figure 7 contains the results of transect samples for *Potamogeton* in East Pool, which contains the largest population of the species. The area occupied by the species began at just over 40 percent when first sampled and increased very slowly to just over 50 percent at the end of year two. The population distribution has declined slowly during year three. The population is presently just below initial levels. The effect on the biomass is more evident. During the first two study years, the population exhibited seasonal biomass peaks through the summer and fall. After the winter biomass decline in year three, the normal summer population increase did not occur. The *Potamogeton* population is still widely distributed in the lake, but its biomass is at a low level.

Figures 8 and 9 show the status of *Nitella* in Middle and West Pools, respectively. *Nitella* exhibits two biomass peaks in late spring and early fall. The population declines briefly during midsummer. Middle Pool has the largest *Nitella* populations in the lake. *Nitella* produces a much greater biomass than any of the other species present in the lake system. The distribution in the pool declined during the first four months of the study and increased during the remainder of the first year. Levels have remained relatively constant since the end of the first year. Some indication of biomass decline is evident. During the baseline year, the biomass peaks were near 1200 g/m^2. During

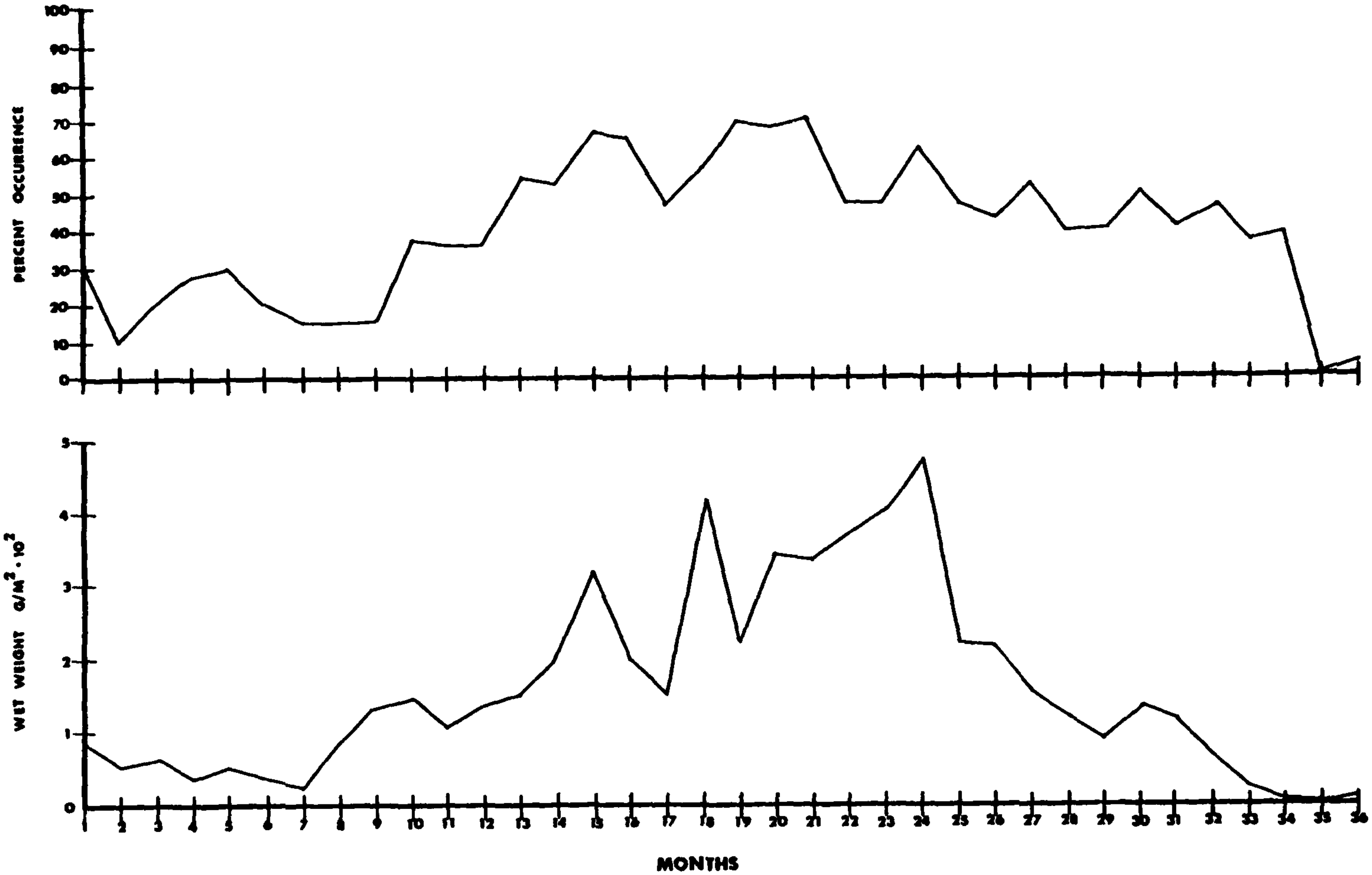

Figure 5. Transect results, *Hydrilla*, South Pool

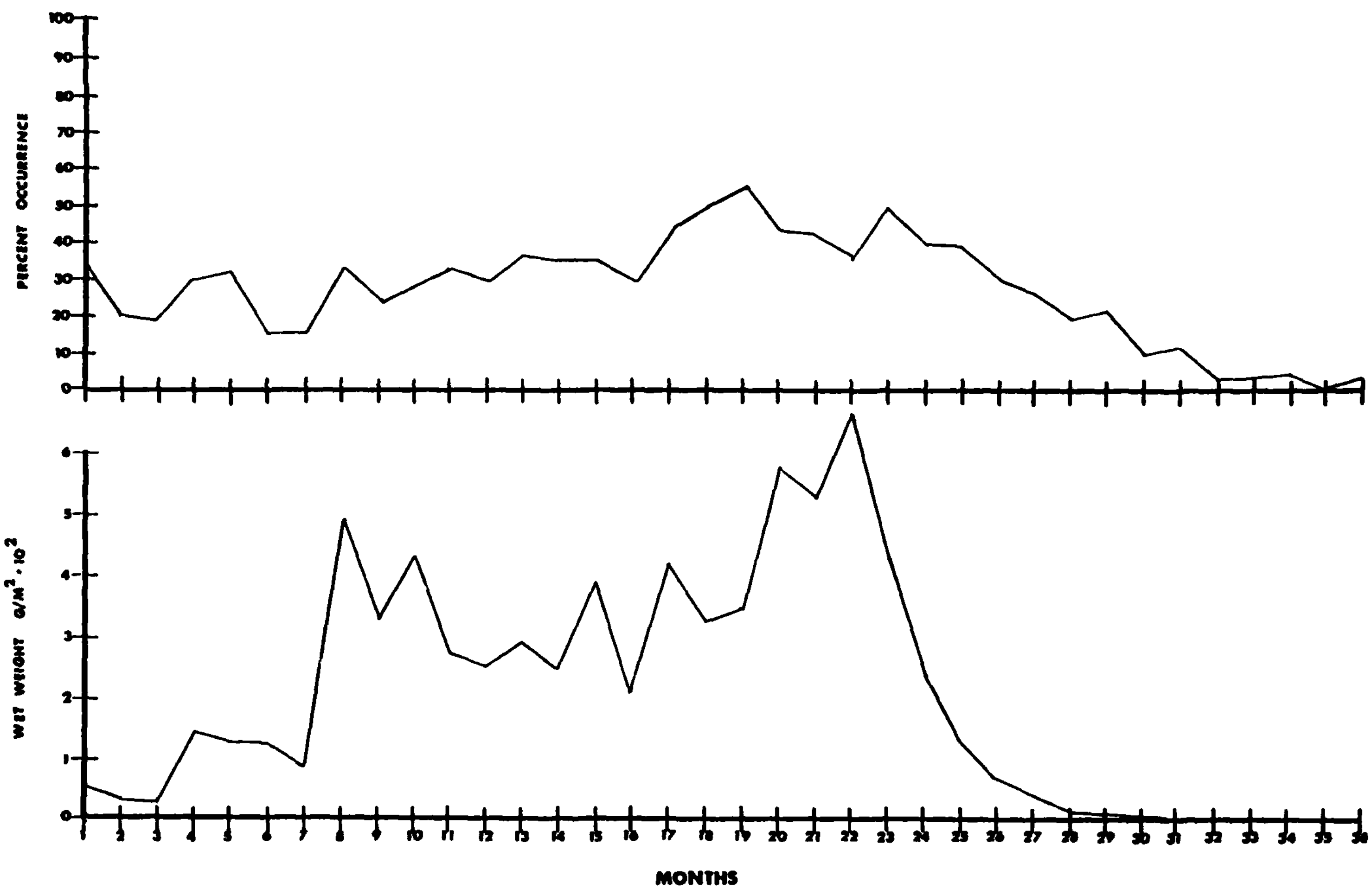

Figure 6. Transect results, *Hydrilla*, West Pool

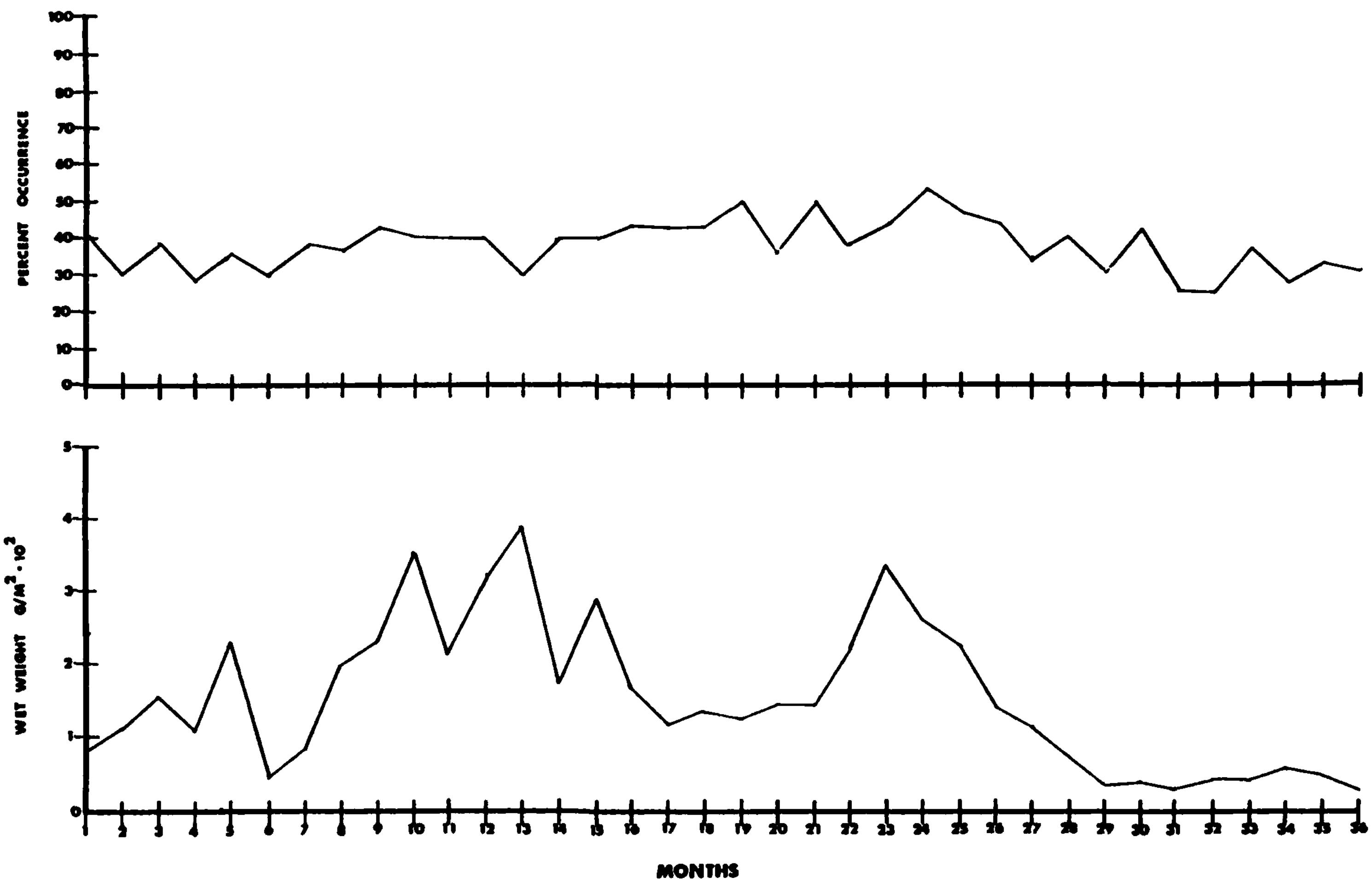

Figure 7. Transect results, *Potamogeton*, East Pool

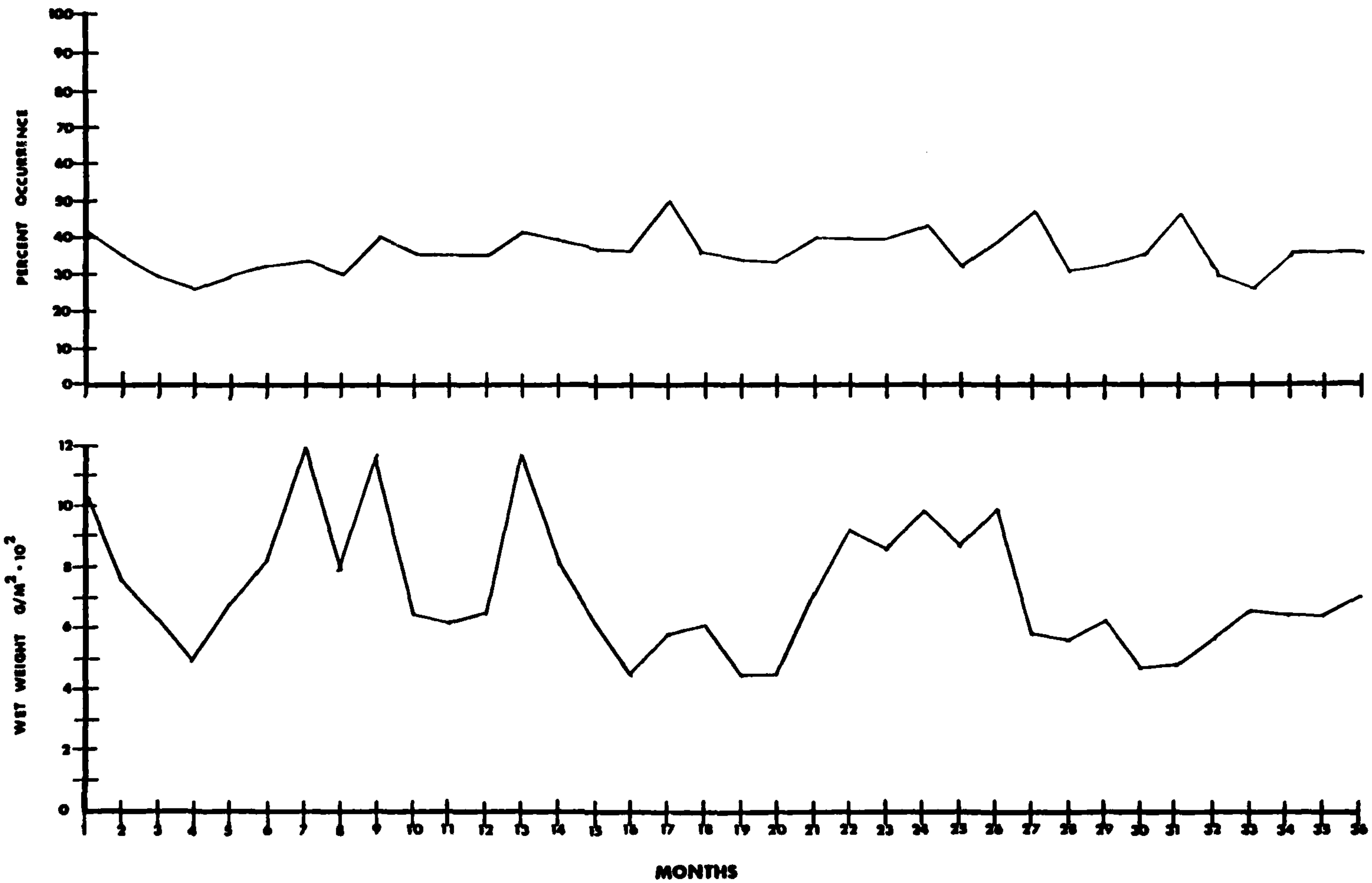

Figure 8. Transect results, *Nitella*, Middle Pool

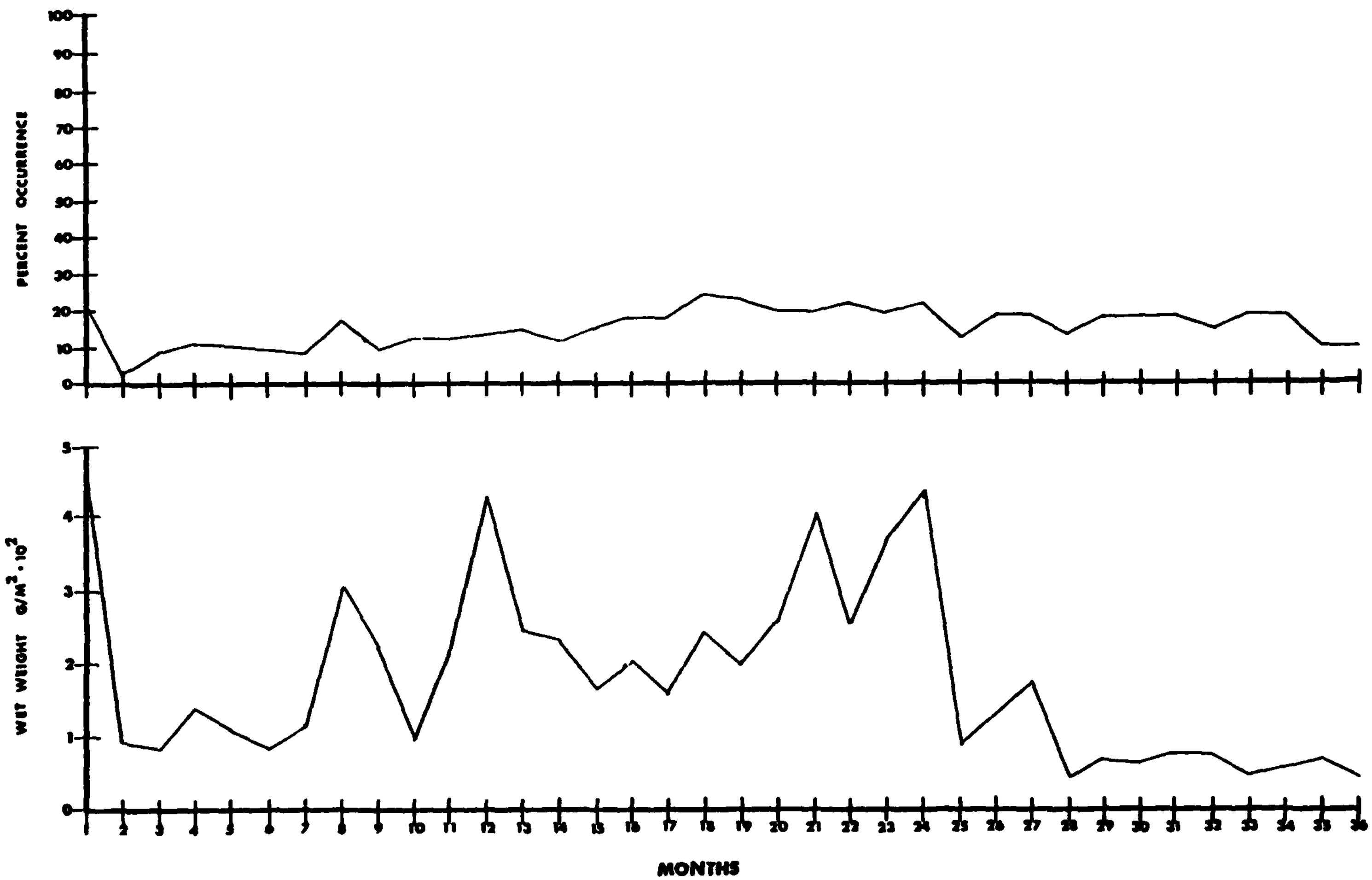

Figure 9. Transect results, *Nitella*, West Pool

year two, the peaks reached about 1000 g/m^2. During the third year, biomass peaked at about 700 g/m^2, only slightly above minimum levels. The effect in West Pool is more evident. The distribution has remained fairly stable since the middle of year two. The decline found in the last two months of the third year may be the first indication of a decline in distribution. West Pool biomass shows a more significant effect. After the seasonal peak at the end of year two, the population declined for the winter as expected. However, the biomass continued to decline and maintained this low level throughout most of the third study year.

Vallisneria is the last of the major species in the lake and the only one that fish do not prefer. Figures 10 and 11 show the reaction of *Vallisneria* in the East and West Pools, respectively, which have the largest eelgrass populations. Although somewhat variable, the percent occurrence of *Vallisneria* was essentially unchanged during the three study years in East Pool. The biomass, which was also highly variable, was highest during the baseline year and lower but unchanged between the second and third test years. The decline occurred too soon after stocking to be attributed to the amur. The effect in West Pool is more interesting. Biomass and frequency of occurrence occurred at low levels until midway through year two when both began to increase steadily. These increases are presumably in response to the decline of other plant species caused by the amur.

Plots

Plot samples (Figures 12-14) show similar results but in greater detail. Plot No. 1 (Figure 12) is located in South Pool. The site has contained an almost total coverage of *Nitella* and a small *Hydrilla* population. The *Hydrilla* occurrence declined midway in the second study year and was eliminated by the end of the third year. The *Hydrilla* population at this site was too sparse to provide consistent height or density data. *Nitella* maintained an almost complete coverage until the final months of the third year when the coverage began to decline considerably. The height also declined to consistently lower levels than previously recorded at the site. Seasonal increases in height were evident in the fall months. Stem density, although variable, showed a steep decline to very low levels during the final months of the third year.

Plot No. 7 (Figure 13) in East Pool when first encountered contained a sparse population of *Hydrilla* with negligible height or stem density. The area had a history of a dense *Hydrilla* mat that had been controlled chemically. By the end of year one, *Hydrilla* had increased to a total coverage; height and stem density were also beginning to increase. By the later months of year two, *Hydrilla* height and stem density had reached substantial amounts, then began to decline steeply. By year three, height and density were minimal and the frequency was beginning to decline. *Hydrilla* was absent from the plot during month 36. Simultaneously with the decline in *Hydrilla* height and density, *Nitella* and *Vallisneria* began to appear rapidly. Within three months,

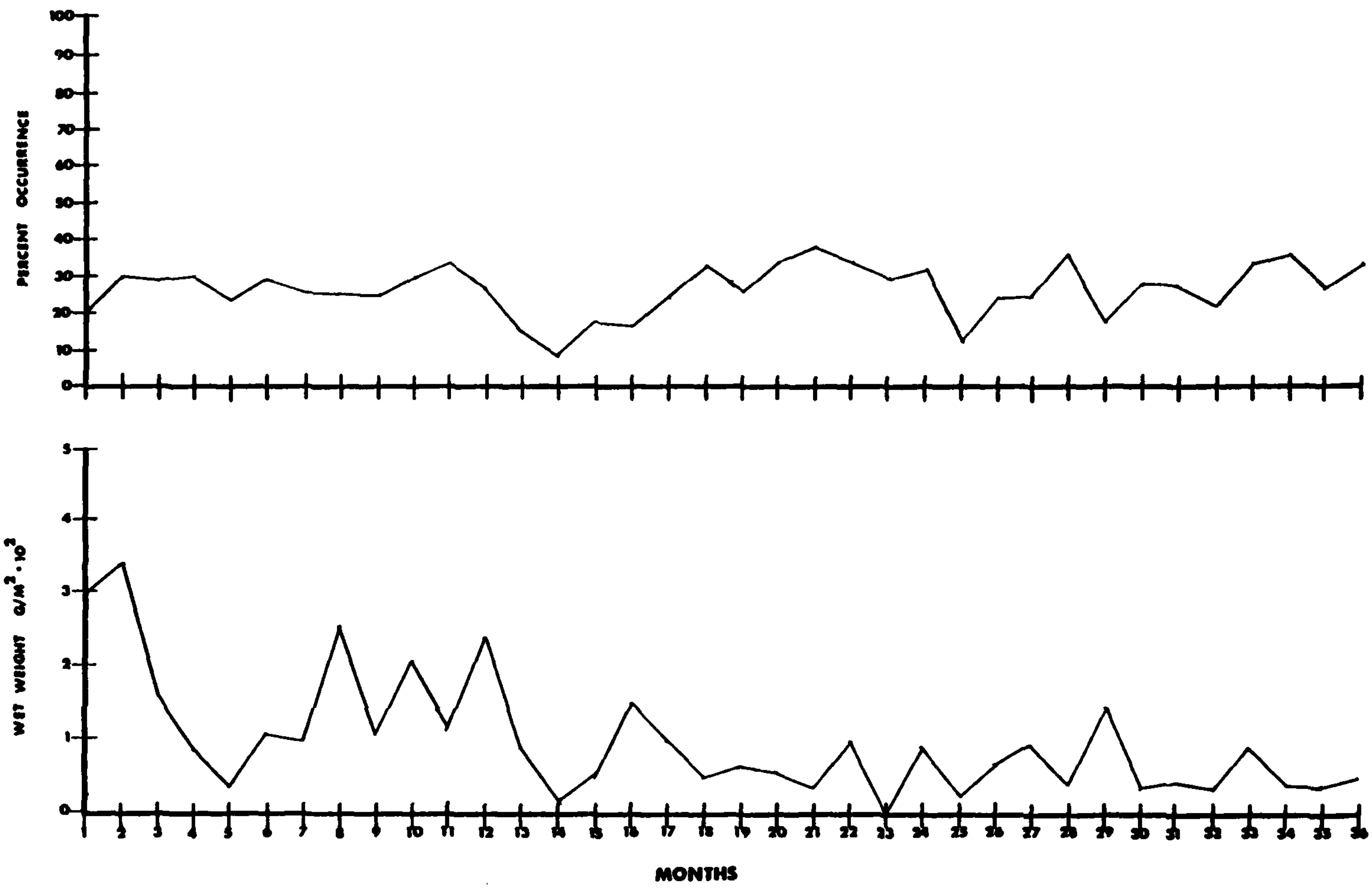

Figure 10. Transect results, *Vallisneria*, East Pool

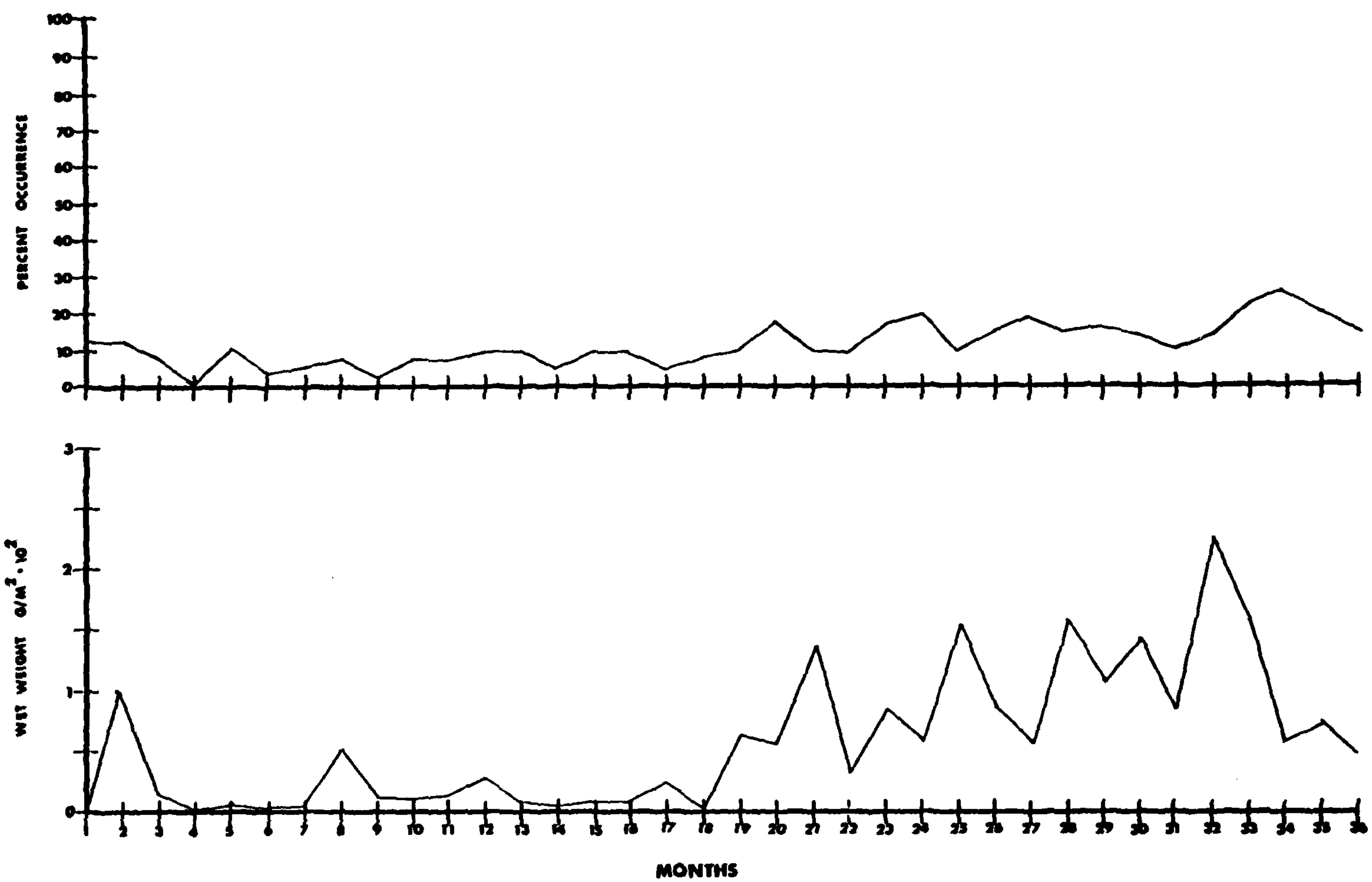

Figure 11. Transect results, *Vallisneria*, West Pool

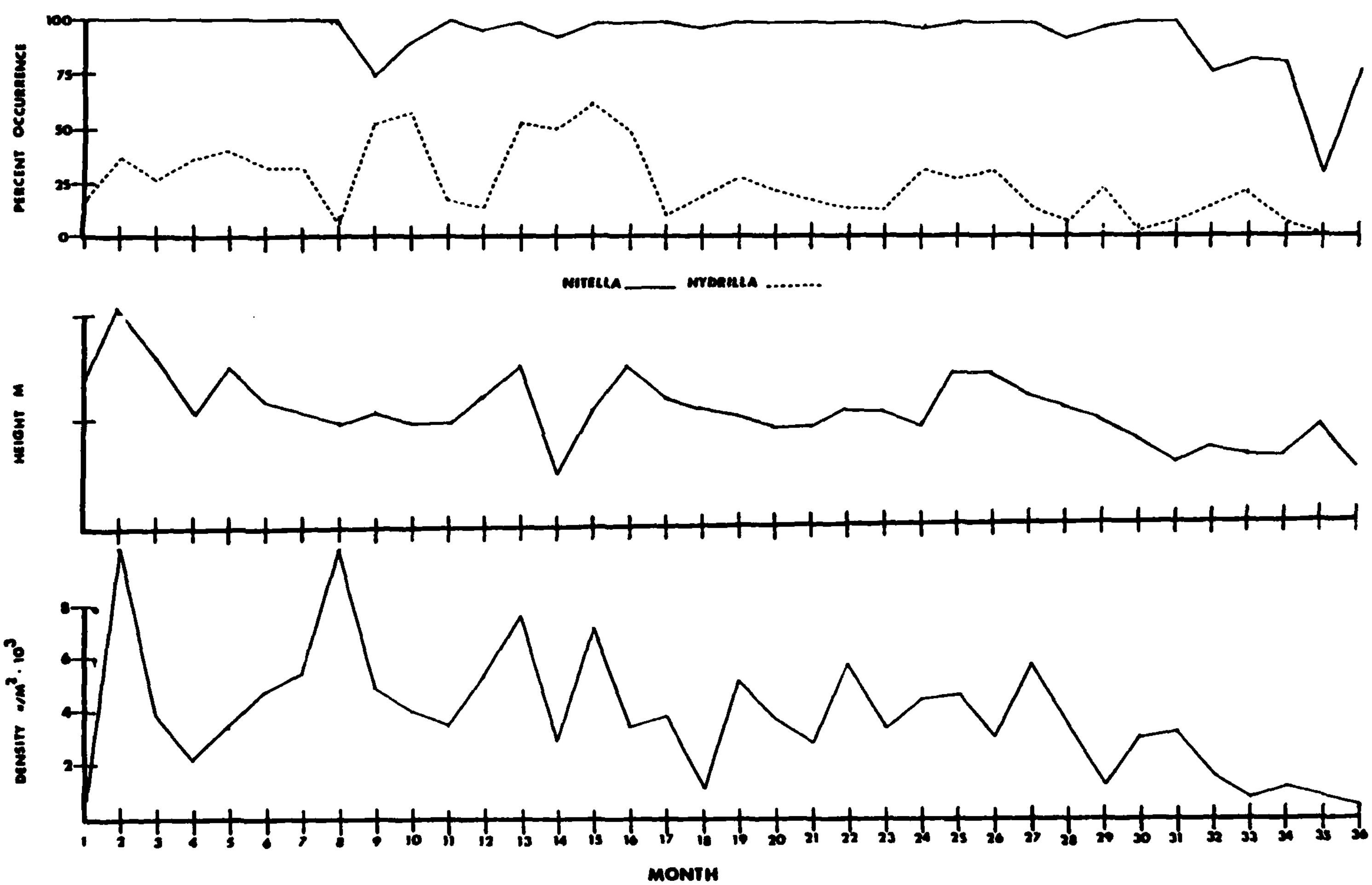

Figure 12. Plot No. 1 results, South Pool

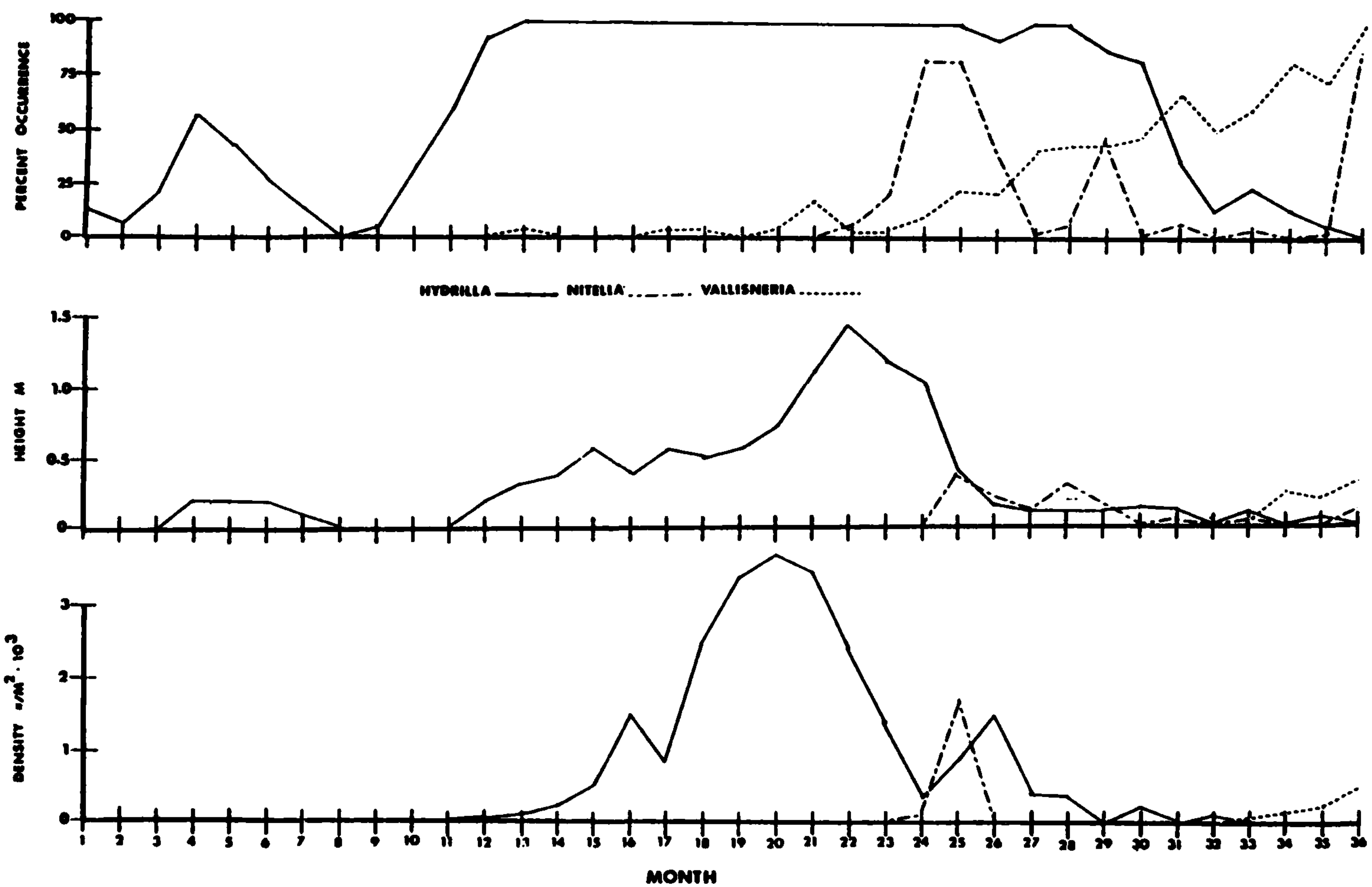

Figure 13. Plot No. 7 results, East Pool

Nitella had developed an 80 percent occurrence and significant heights and density, but in an equal period *Nitella* was reduced to miminal values. Presumably, the amur had greatly reduced the *Hydrilla* and then turned to the increasing *Nitella* population. Meanwhile, the *Vallisneria* was increasing to a near 100 percent occurrence and developing significant heights and density, apparently in response to the absence of its competitors and without effect from the amur.

Plot No. 10 (Figure 14) in West Pool was located in one of the most dense *Hydrilla* populations in the lake system. *Hydrilla* dominated the site during year one, but declined while *Nitella* and *Vallisneria* began increasing. During year two, *Hydrilla* declined to minimal levels. The trend of declining *Hydrilla* and increases in other species began during the baseline and thus was not initially due to the amur, but the rapid decrease in all parameters at the end of year two probably was due to the fish. As in plot No. 7, *Nitella* increased rapidly but as the *Hydrilla* disappeared the *Nitella* was soon affected. Again, *Vallisneria* was not affected.

Vegetation mapping

Figure 15 shows a map of the vegetated area of Lake Conway with the percent cover of each pool indicated. Figure 16 shows a similar map of the distribution of *Hydrilla*. Both maps were made just prior to stocking. The maps were prepared by running closely spaced transects with a recording fathometer and were supplemented by data from all other sampling techniques. Figure 17 shows a similar map of the total vegetation cover prepared near the end of the third study year. Changes relative to the baseline map are indicated. Middle and East Pools show little change. The decrease occurred in South and West Pools, which contained the only large populations of *Hydrilla*. The absence of *Hydrilla* is responsible for the change. Figure 18 shows a map of the present distribution of *Hydrilla*. Compared to Figure 16, the difference is obvious. Although *Hydrilla* still occurs sparsely in much of the lake, no significant populations exist worthy of recording.

Discussion

The results presented are clear and easily interpreted. All sampling techniques have shown the near elimination of *Hydrilla*, the target species, throughout the Lake Conway system. In a classic demonstration of feeding preference, *Hydrilla*, where present, was greatly reduced before the other species were affected. After the reduction of *Hydrilla*, *Nitella* and *Potamogeton* have also shown major effect but large populations of these species still remain. *Vallisneria*, a nonpreferred species, has shown definite increases. The elimination of or increased stress on competitive species by the amur has allowed *Vallisneria* to flourish.

From the viewpoint of demonstrating the vegetation control capacity

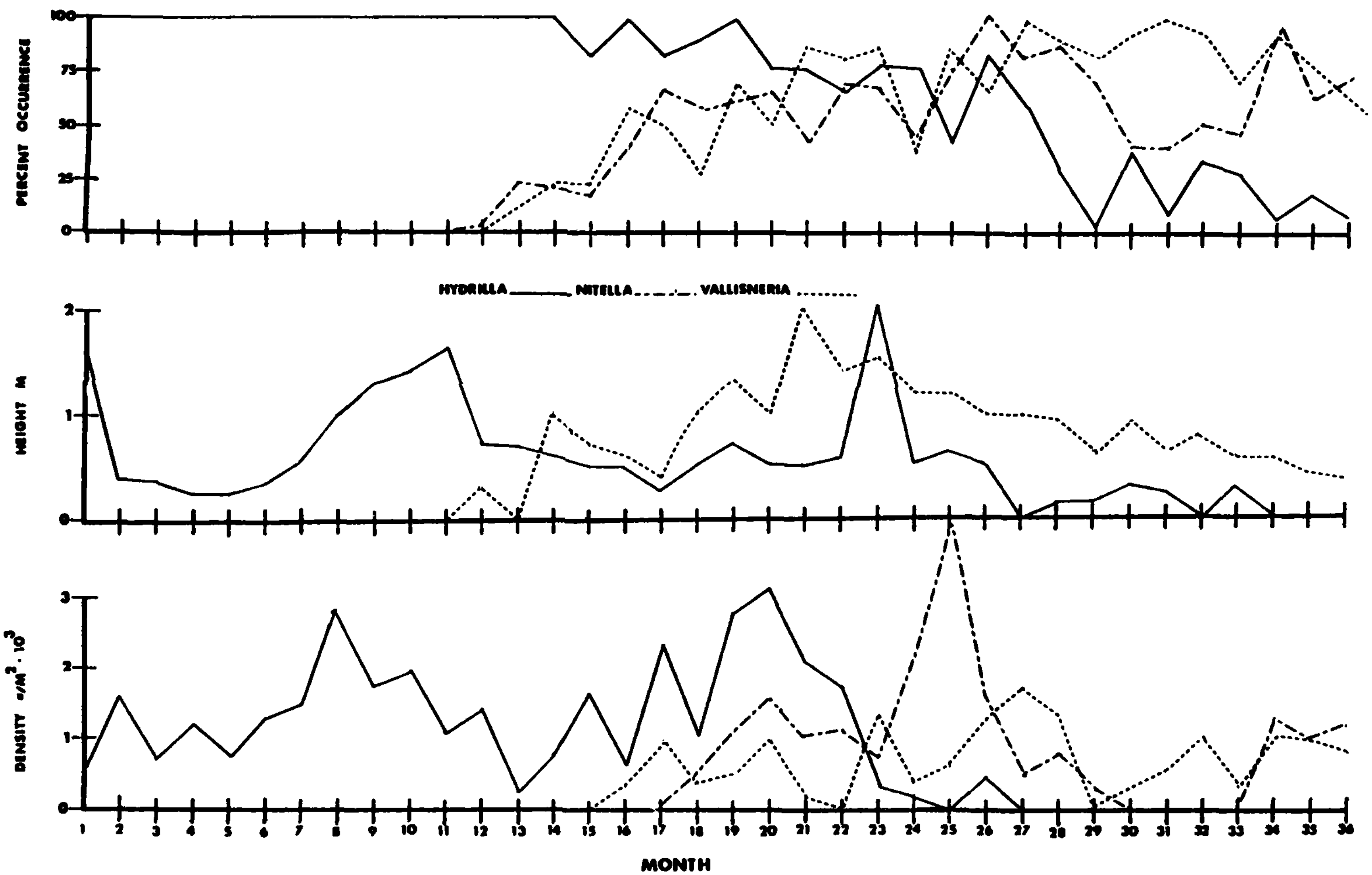

Figure 14. Plot No. 10 results, West Pool

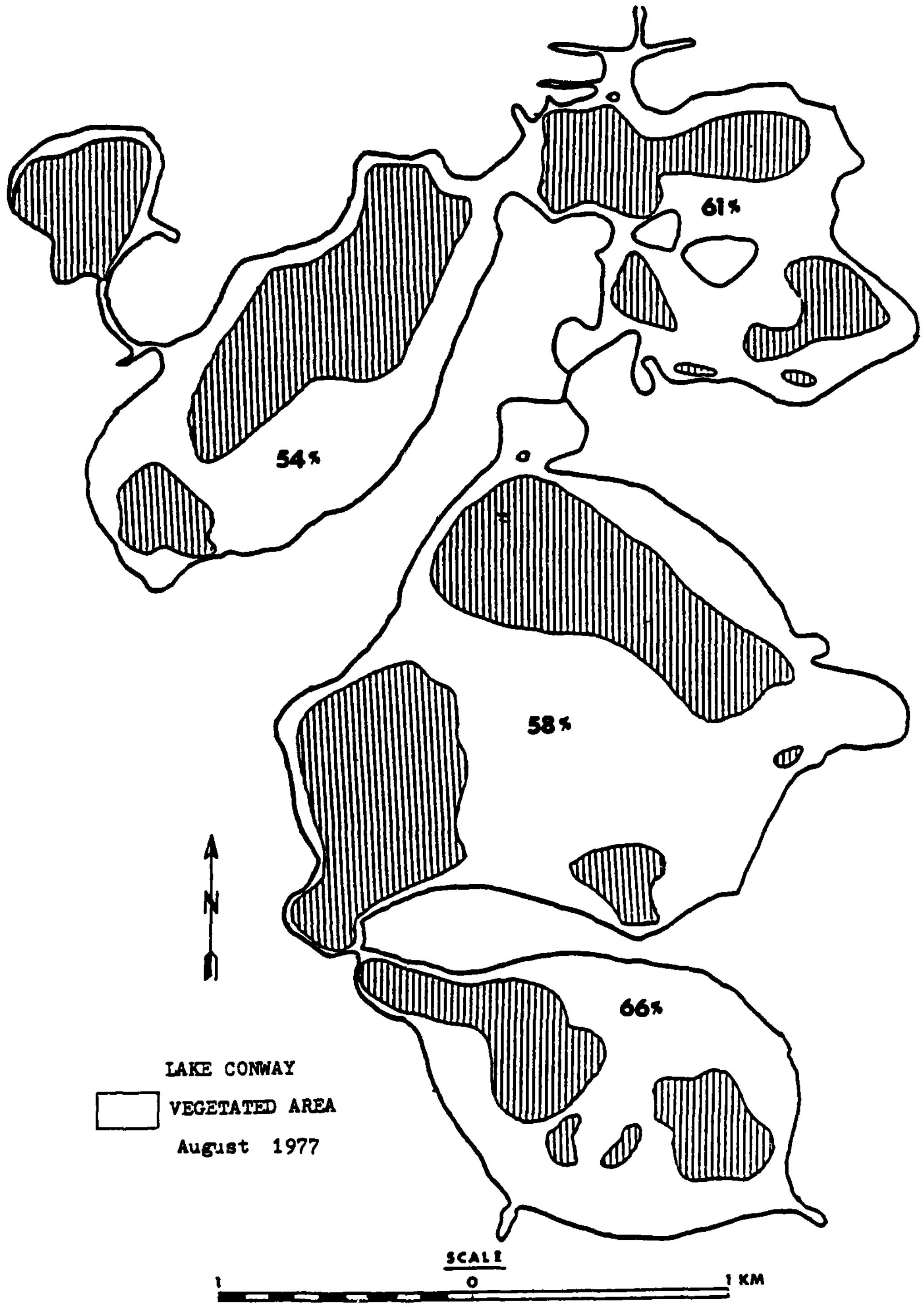

Figure 15. Vegetated area of Lake Conway prior to stocking

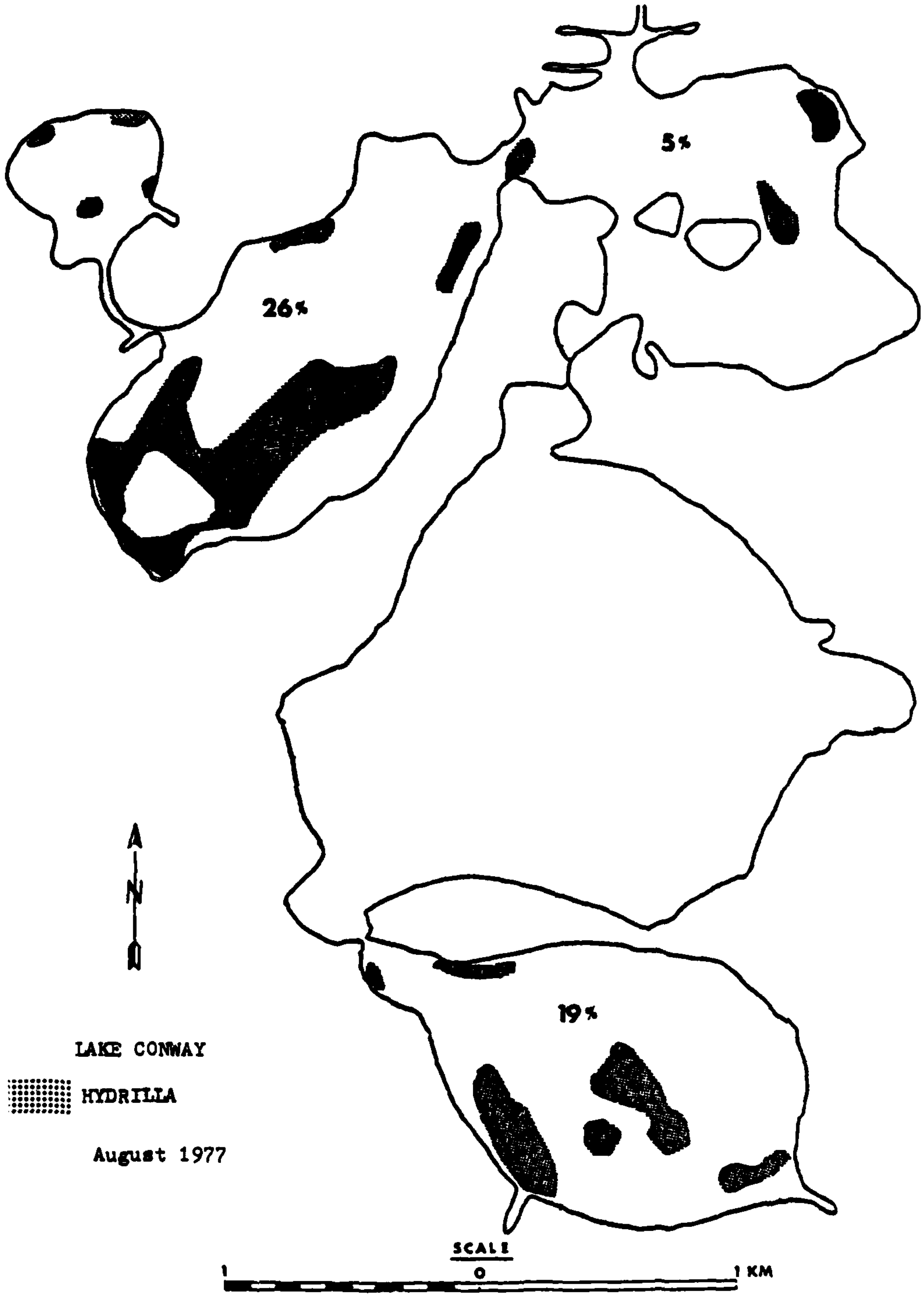

Figure 16. Distribution of hydrilla in Lake Conway prior to stocking

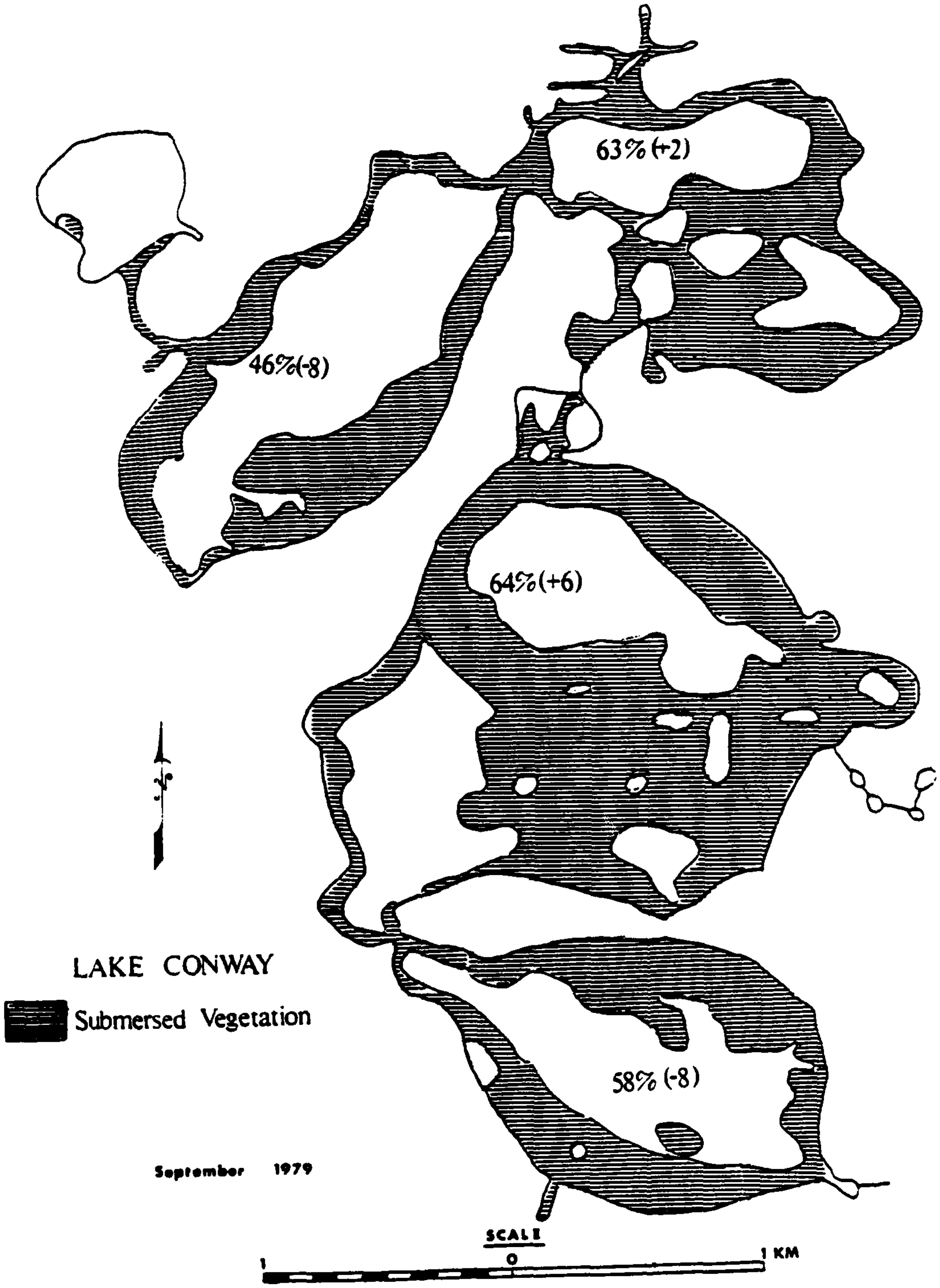

Figure 17. Vegetated area of Lake Conway at the end of the third study year

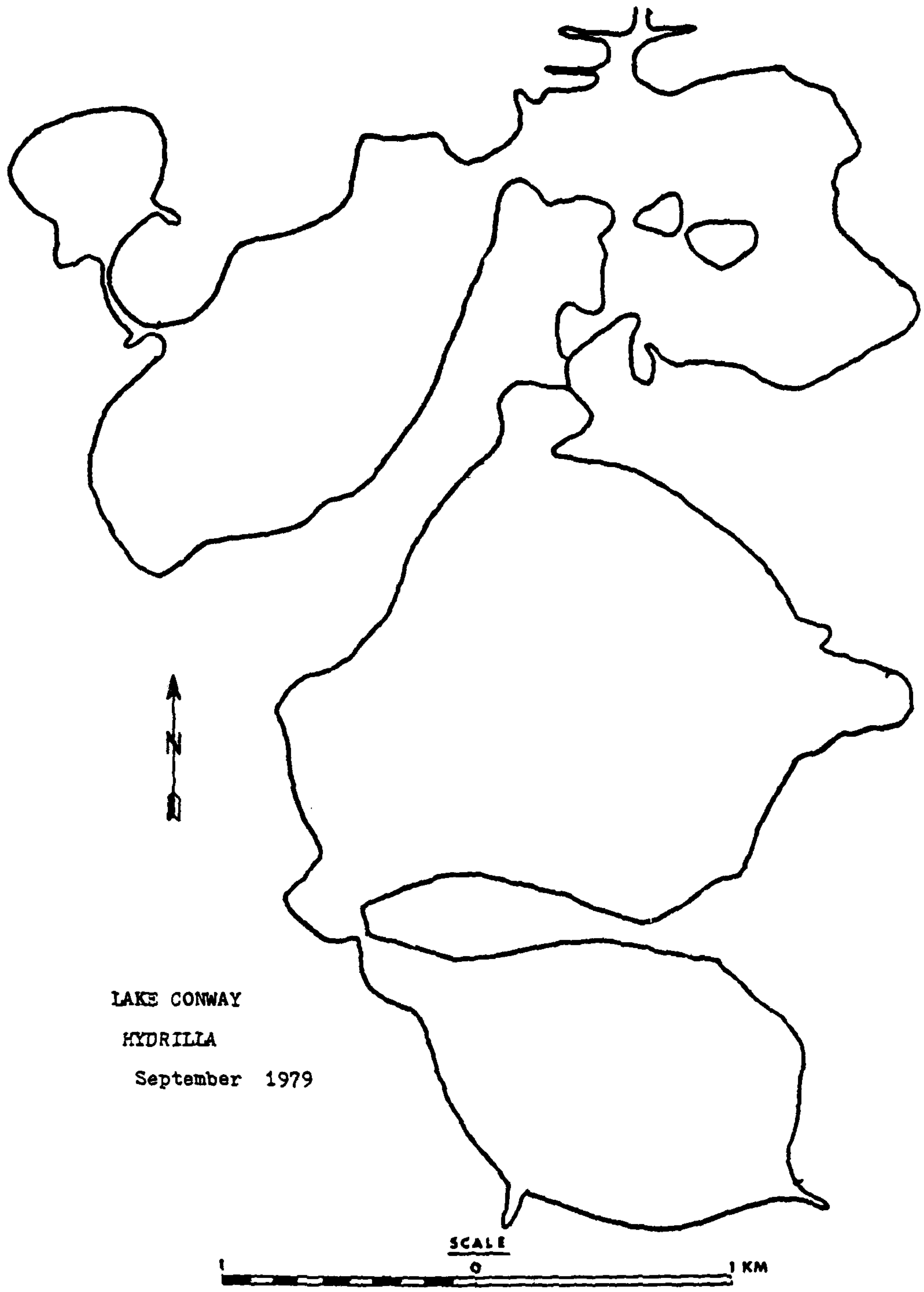

Figure 18. Distribution of *Hydrilla* in Lake Conway, September 1979

of the white amur, the project can already be called successful. The undesirable species *Hydrilla* has been practically eliminated. The effect on other more desirable submersed species has not been fully determined. Trends are indicating declines in *Nitella* and *Potamogeton*, and elimination or drastic reduction of these species is probable. Should these species be removed, the effect on *Vallisneria* and the marginal species, which are not preferred by the fish, is uncertain. In overstocked situations, the elimination of submersed vegetation was followed by the removal of the shoreline vegetation.* It is not known, as yet, if this same effect will occur in Lake Conway, which was stocked at a much lower rate.

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* Miley, W. W., II, Leslie, A. J., Jr., and Van Dyke, J. M. 1979. "The Effects of Grass Carp (*Ctenopharyngodon idella* Val.) on Vegetation and Water Quality in Three Central Florida Lakes." Final Report, Florida Department of Natural Resources, Bureau of Aquatic Plant Research and Control, Tallahassee, Florida.

LARGE-SCALE OPERATIONS MANAGEMENT TEST USING THE WHITE AMUR AT LAKE CONWAY, FLORIDA

Fish, Mammals, and Waterfowl

by

Roy Land*

Introduction

Florida's warm climate is conducive to the growth of aquatic plants. Many varieties of exotic plants have been imported and introduced into Florida's waterways where they have become a nuisance by impeding navigation, reducing angler access, and replacing beneficial native aquatic plants within the ecosystem. Hydrilla (*Hydrilla verticillata*), the most common pest plant in the southeastern United States (Hamilton 1976),** is found in 280,000 ha in Florida (Haller 1977).

Native aquatic plants serve several beneficial functions: nursery for juvenile fish; nesting sites for many bird species; habitat for invertebrate organisms that are a source of food for fish; a sump for nutrients that would otherwise be converted to phytoplankton; and shelter for many fish, birds, and aquatic mammals. Increased nutrient levels may produce an increase in phytoplankton and could possibly shift the standing crop relation.

Mechanical removal of problem plants has proved to be too expensive because continued harvesting is usually required. Chemical control is usually less expensive than mechanical harvesting, but long-range effects on the ecosystem have not been determined; therefore, only a few herbicides have been approved for use in public water systems (Graves 1976).** Both methods are short term; a biological control agent is most appealing because, ideally, once the agent is established, no further control is required.

Many agents have been tested, and an exotic fish, the white amur, or grass carp (*Ctenopharyngodon idella*), appears most promising for control of hydrilla (Cross 1969). Its consumption of large quantities of hydrilla has been documented by Avualt (1965) and Sutton (1974).

This report deals with fish, waterfowl and wading birds, and aquatic mammal populations 1 year prior and 2 years after stocking of 3.9 grass carp per acre in Lake Conway.

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* Florida Game and Fresh Water Fish Commission, Tallahassee, Florida.

** National briefing on the white amur research project, Lake Conway, Florida. Washington, D. C. 27 April 1976.

This study will help to determine the effects of grass carp as a control agent for problem vegetation.

Description of Study Area

Lake Conway is a 747-ha chain of five natural lakes in Orange County, Florida. Mean lake elevation is 25.7 m msl (mean sea level), mean annual temperature is 22°C, and average rainfall is 131 cm (Guillory et al. 1977). The chain, in the northern portion of the Kissimmee River drainage basin, has one inlet and one outlet stream. Considerable urbanization and shoreline development has replaced much of the natural vegetation with white sand beaches; however, cattails (*Typha latifolia*), maidencane (*Panicum hemitomon*), pickerelweed (Pontederia *cordata*), and furiena (*Furiena scirpoides*) form a fringe of emergent vegetation in parts of the lake. Dominant submerged vegetation at present includes nitella (*Nitella* sp.), Illinois pondweed (*Potamogeton illinoensis*), and hydrilla. Bottom substrate is primarily sand with some areas of organic deposition.

Methods and Materials

Fish populations

Fish populations were sampled using five methods: electrofishing, Wegener rings, gill nets, blocknet, and creel survey.

Electrofishing was utilized to compare fish populations from vegetated and nonvegetated beach sites; 30-min sampling periods were conducted for each habitat type at each of four sites.

Wegener rings (Wegener, Holcomb, and Williams 1973) were used to sample shallow water fish populations. Each sample covered 0.00247 ha; two samples were taken at each of six sites. Rotenone was applied at approximately 2 mg/ℓ and all fish removed, sorted by species, grouped into 10-mm size classes, and weighed to 0.01 g.

Two 45.7-m gill nets (stretch varied from 5.08 to 15.24 cm) were set for 12 hr from 1976-1978 and for 48 hr during 1978-1979. Fish captured were sorted to species, counted, and weighed to 0.01 g.

Blocknet samples (0.4 ha) were taken biannually at three sites. Rotenone was applied at 2 mg/ℓ, and all fish were collected, sorted to species, grouped in 2.54-cm size classes, counted, and weighed.

A stratified random roving creel survey utilizing nonuniform probability sampling was used to measure the sport fishery. Creel data were analyzed by the Southeastern Cooperative Game and Fish Statistics Project, Raleigh, North Carolina.

Stomach contents from largemouth bass (*Micropterus salmoides*),

bluegill (*Lepomis macrochirus*), and bluefin killifish (*Lucania goodei*) were examined and enumerated. Foregut contents (from esophagus to the first turn) of grass carp were examined; items were quantitated visually, or, where two or more items were present in more than trace amounts, by water displacement.

Waterfowl and wading birds

Waterfowl and wading birds were counted monthly from an airboat. Migratory waterfowl were collected by shotgun during winter months; gizzards were removed and food habits determined. Percentages of each item were determined visually or volumetrically when possible.

Aquatic mammals

Visual surveys of aquatic mammals were conducted during the baseline year and several museum traps were set during one week (7-11 March 1977). Systematic trapping was conducted during both poststocking years: Tomahawk double-door treadle operated traps were baited with fish to sample larger mammals (raccoon, *Procyon lotor*; opossum, *Didelphis marsupials*); Sherman traps (3.5 by 3.5 by 9 cm) were baited with peanut butter to capture hispid cotton rats (*Sigmodon hispidus*) and rice rats (*Iryzomys palustris*). Because Florida water rats (*Neofiber alleni*) are relatively invulnerable to capture by conventional traps (Birkenholz 1963), specially constructed traps were placed in this animal's nests. Monthly counts were made of Florida water rat nests at four sites; nest material, surrounding vegetations, and water depth were noted. Percentage of vegetation at each site was estimated visually.

Fish Population Results

The results for the fish population studies are given in the following paragraphs.

Electrofishing, vegetation

Year I - 1976-1977 (prestocking). Vegetation samples averaged 164 fish per hour weighing 17.42 kg. The species that yielded the largest numbers and weights were chain pickerel (*Esox niger*), brook silverside (*Labidesthes sicculus*), warmouth (*Lepomis gulosus*), bluegill, redear sunfish (*Lepomis microlophus*), and largemouth bass.

Year II - 1977-1978 (poststocking). Vegetation samples produced an average of 181.35 fish and 7.71 kg in weight. The species yielding the largest numbers were bluegill, redear, and largemouth bass. The species producing the most weight were largemouth bass, chain pickerel, and redear sunfish.

Year III - 1978-1979 (poststocking). Electroshocking samples on vegetative sites increased in numbers and weights. Average number of fish taken per hour increased from 181.35 (1977-1978) to 293.23 (1978-1979), an increase of 16.2 percent. Weight per hour increased to 7.71 kg, an increase of 199 percent.

Low water levels part of the year hampered, if not nullified, all stocking efforts at certain sites. With the return of higher water, fish appeared to be concentrated within the littoral zone. The greatest weight increase was due to grass carp and largemouth bass. Grass carp weight per hour increased from 1718.49 kg (Year II) to 3476.17 kg (Year III) per hour. Number of individuals captured increased with the higher water levels.

Electrofishing, beach

Year I - 1976-1977 (prestocking). An average of 436 individuals per hour weighing 12.25 kg were collected on beaches. By number, brook silversides, bluegill, and redear were the most often collected. Bluegill, redear, and largemouth bass produced the most weight.

Year II - 1977-1978 (poststocking). The average number of individuals was 484 with an average weight of 5.37 kg. Brook silversides produced the largest numbers while largemouth bass, redear sunfish, and bluegill produced the greatest weights.

Year III - 1978-1979 (poststocking). Individuals averaged 695 and weighed an average of 6.67 kg. Average numbers increased by 59 percent from Year I and 44 percent from Year II. Average weights decreased by 56 percent from Year I and 46 percent from Year II.

The first year there were fewer beaches, which confined the fish that utilized them. These fish were easier to capture. Shoreline development has expanded beach habitats, which makes sampling more difficult.

Wegener ring

Year I - 1976-1977 (prestocking). Wegener ring samples yielded an average of 20.87 fish, weighing 11.52 g per collection. Numerically, mosquitofish (*Gambusia affinis*) and bluefin killifish (*Lucania goodei*) comprised 68 percent of the total. Seminole killifish (*Fundulus seminolis*) had the largest average weight per sample, followed by mosquitofish, bluefin killifish, warmouth, and bluegill.

Year II - 1977-1978 (poststocking). Average number of fish per sample declined from the baseline year; however, the weight per collection was almost identical to that of the previous year. The average number of fish was 14.92 per sample and the average weight was 11.53. Mosquitofish, bluefin killifish, and Seminole killifish were the most abundant species collected. Seminc_e killifish and mosquitofish yielded the most weight. More bluefin killifish were observed than in 1976-1977, and yellow bullhead (*Ictalurus natalis*) and sailfin mollie (*Poecilia latipinna*) were captured for the first time in 1977-1978.

Year III - 1978-1979 (poststocking). The average number and weight per sample decreased from the previous year. The average number per sample was 11.1 and the weight averaged 10.7. Mosquitofish and Seminole killifish were the principal species captured in Wegener ring samples in 1978-1979. Seminole killifish and bluegill produced the greatest weight.

This decrease was due to lower water levels, which eliminated some of the most productive sampling sites in Lake Gatlin. Shoreline development forced a change in sampling sites to less desirable locations.

Gill nets

Year I - 1976-1977 (prestocking). Thirty-one specimens per net day (24 hr) weighing 17.78 kg were taken in gill nets. Florida gar (*Lepisosteus platyrhincus*), gizzard shad (*Dorosoma cepedianum*), and largemouth bass were the three dominant species in terms of both numbers and weight.

Year II - 1977-1978 (poststocking). Twenty-six specimens per net day were sampled weighing an average of 15.65 kg, with chain pickerel, largemouth bass, and bluegill the most dominant by number. Florida gar, largemouth bass, and gizzard shad produced the most weight.

Year III - 1978-1979 (poststocking). All species declined in numbers and weights from Year I and Year II. Number of species per gill net day averaged 11.78 with an average weight of 8.06 kg. Largemouth bass was the most common species captured with an average weight of 4.88 kg per gill net day. Largemouth bass, gizzard shad, and Florida gar combined comprised 79.19 percent of the total numbers and 80.36 percent of the weight.

Modification in sampling methods by using a larger mesh size net reduced the efficiency in capturing smaller fish. Another modification involved changing from a 12-hr set to a 48-hr set. Averages were smaller when done this way. Fish appeared to move more at night and this also lowered the averages. There were no apparent changes in the pelagic fish populations.

Blocknet

Year I - 1976-1977 (prestocking). Sportfish averaged 7,227.1 fish/ha with a weight of 82.67 kg. Forage species averaged 29,364.4/ha and weighed 19.13 kg/ha. Other species included the Florida gar, lake chubsucker (*Erimyzon sucetta*), brown bullhead (*Ictalurus nebulosus*), and yellow bullhead, which yielded an average of 225.6 individuals weighing 18.7 kg/ha. Average number and weight per net was 41,635.4 and 103.17 kg, respectively.

The most abundant species included bluespotted sunfish, bluegill, redear sunfish, bluefin killifish, and largemouth bass. Forage species dominated samples numerically, and the sportfish comprised the major portion of weight.

Sportfish include the largemouth bass, black crappie (*Pomoxis nigromaculatus*), bluegill, redear sunfish, warmouth, and chain pickerel. Forage species include the threadfin shad (*Dorosoma petenense*), golden shiner (*Notemigonus crysoleucas*), coastal shiner (*Notropis petersoni*), tadpole madtom (*Noturus gyrinus*), flagfish (*Jordanella floridae*), least killifish (*Heterandria formosa*), bluespotted sunfish (*Enneacanthus gloriosus*), dollar sunfish (*Lepomis marginatus*), and swamp darter (*Etheostoma fusiforme*). Other species include the Florida gar, lake

chubsucker, brown bullhead, and yellow bullhead.

Year II - 1977-1978 (poststocking). Sportfish averaged 7,747.8 fish/ha and weighed 76.7 kg. Forage species averaged 29,914.2/ha, which weighed 31.8 kg. Other species averaged 76.2 individuals and weighed 1.1 kg. Blocknet data indicated sportfish comprised the majority of the estimated standing crop of 109.2 kg/ha, even though bluespotted sunfish dominated numerically with 63 percent, but comprised only 15 percent by weight. Average number of individuals per net was 37,737.3.

Year III - 1978-1979 (poststocking). Sportfish averaged 8,965 fish/ha which weighed 83.8 kg. This was an increase of 20 kg from Year II and an increase of 1.1 kg from Year I. The forage species averaged 28.593 and weighed an average of 34.6 kg. Other species averaged 302.5/ha and weighed 2.5 kg. Average number and weight per net was 38,099.74 and 128.6 kg, respectively.

Sportfish increased numerically each year following Year I. The sportfish weight for Year II was slightly less than Year I but was slightly larger for Year III. Forage species did not change appreciably between the three years. Other species showed no trend between the three years. No apparent change had occurred in the fish population on Lake Conway.

Creel

Data are not available at this time.

Largemouth bass food habits

Year I - 1976-1977 (prestocking). Fourteen fish species, *Palaemonetes*, Gomphidae, and Physidae were consumed by largemouth bass. An average of 106.9 prey organisms weighing 470.4 g were found per 100 fish.

Fish remains comprised the largest category of food items--43.4 percent by number and 14.4 percent by weight. As a group, fish totaled 80.6 percent by number and 85.7 percent by weight. The most common fish prey, in order of numerical abundance, included threadfin shad, largemouth bass, bluespotted sunfish, bluegill, and redear sunfish.

Procambarus and *Palaemonetes* were important invertebrate food items, with Gomphidae, Physidae, and Insectra of little significance. Crayfish ranked third in biomass, second in numerical abundance, and first in frequency of occurrences for all identified categories.

Year II - 1977-1978 (poststocking). Largemouth bass were primarily piscivorous, with unidentified fish remains most abundant numerically. Almost 35 unidentified fish were found per 100 stomachs. Crayfish (*Procambarus* sp.) was the second most abundant item followed by brook silverside and grass shrimp (*Palaemonetes paludosus*). Threadfin shad declined in number from 1976-1977, and no cannibalism was found during 1977-1978. By weight, redear sunfish was the principal food item and bluegill, unidentified fish, sirens (*Siren lacertina*), and unidentified *Lepomis* followed in importance. Unidentified fish was the food item most often

encountered, found in 29 percent of stomachs examined. Crayfish was second in frequency of occurrence, with no other organisms found in more than 5 percent of the bass examined.

Year III - 1978-1979 (poststocking). Eight species of identifiable fish were preyed upon by largemouth bass totaling 53.99 percent by number and 90.23 percent by weight. Food items ranked in order of observance following identifiable fish were: unidentified fish, copepods, grass shrimp, and crayfish.

Overall, bass food habits apparently have not changed. Smaller fish were examined this year; therefore, smaller food items (copepods) appeared to be of a greater importance.

Bluegill food habits

Year I - 1976-1977 (prestocking). A total of 27 taxonomic categories, based on the lowest level of identification, were found in bluegill stomachs examined. A range of 12 to 141 food organisms was found in the individuals examined.

Dominant groups of food organisms by number were Chironomidae (36.9 percent), eggs (21.6 percent), Cladocera (13.4 percent), and Trichoptera (13.4 percent). Other common dietary items included vegetative matter, Protozoa, Ostracoda, Gastropoda, Amphipoda, and Clicidae.

Year II - 1977-1978 (poststocking). Crustaceans were the most abundant item in bluegill diets (53 percent) with cladocerans, copepods, and amphipods increasing in number compared to 1976-1977. The percentage of crustaceans increased by 33 percent from the baseline year.

Insects comprised 36 percent by number of bluegill food items: chironomid larvae and pupae constituted over 99 percent of this category.

Crustaceans were observed in 98 percent of bluegill stomachs examined, with amphipods the most common category. Insects were found in 95 percent of all fish examined; dipterans were the most common order (84 percent) and chironomids the most often encountered family (74 percent). Other common items were Trichoptera larvae, hydracarinids, and planorbidae snails.

Year III - 1978-1979 (poststocking). Chironomidae was the most important food item, occurring 1,199.72 times per 100 fish examined. Amphipoda, Trichoptera, and Ostracoda ranked second, third, and fourth, respectively, in value as food items.

There was no major change in bluegill food habits from Year II, but a slight increase was noted in number of items from Year I.

Bluefin food habits

Year I - 1976-1977 (prestocking). A total of 23 food categories were found. An average of 2,023 food organisms were found per 100 fish. Cladocera dominated in stomachs, yielding 1,019 organisms per 100 fish (50.46 percent). The only other groups that comprised more than

10 percent of the total were Ostracoda and Chironomidae. Other common food organisms included Copepoda, Amphipoda, Hydracarina, and eggs.

Year II - 1977-1978 (poststocking). Crustaceans dominated in stomach contents of bluefin killifish (79 percent by number) followed by insects (17 percent). Ostracods were the most numerous prey items, comprising 42 percent by number of the diet occurring in 48 percent of fish examined. Copepods were the second most abundant item and were found in 40 percent of bluefin killifish stomachs. Chironomid larvae were the principal insect by number consumed constituting 15 percent of the diet.

Year III - 1978-1979 (poststocking). Cladocera occurred 309.4 times per 100 fish (39 percent). Copepoda were second in frequency of occurrence, identified 135.3 times per 100 fish. Chironomidae were the most important insect food item encountered.

Food habits of bluefin killifish have not changed drastically from Year I and II.

White amur food habits

Year II - 1977-1978 (poststocking). Grass carp fed almost exclusively on vegetation. Sixteen fish less than 500 mm were sampled and they preferred hydrilla, while larger specimens had consumed principally Illinois pondweed and *Nitella*. Other plant species and animal food were taken in negligible amounts.

Year III - 1978-1979 (poststocking). Of the 25 fish examined, 34.83 percent of the food consumed was filamentous algae. *Nitella* (30.42 percent), Illinois pondweed (16.88 percent), and hydrilla (12.21 percent) comprised the majority of the bulk. Animal foods were found in trace amounts.

Six fish were captured in a somewhat isolated (one narrow entrance) cove and all had consumed large amounts of filamentous algae; this accounted for a change in food preference from Year II. These six fish were an isolated situation and probably do not represent a true preference in food vegetations. Food preference appears to have shifted from Illinois pondweed to *Nitella*. This shift is most likely due to a loss of Illinois pondweed in Lake Conway.

Waterfowl and Wading Birds Results

Sampling results

Year I - 1976-1977 (prestocking). A total of 50 species and an average of 1,981 individuals per month were observed. The ten most abundant species were ring-neck duck (*Aythya collaris*), muscovy duck (*Cairina moschata*), American coot (*Fulica americana*), Florida gallinule (*Gallinula chloropus cachinnans*), herring gull (*Larus argentatus*), mallard duck (*Anas platyrhynchos platyrhynchos*), least tern (*Sterna*

albifrons), tree swallow (*Iridoprocne bicolor*), red-winged blackbird (*Agelaius phoeniceus*), and boat-tailed grackle (*Cassidix mexicanus*); each averaged more than 20 individuals per month and, when totaled, comprised 88.48 percent of the total avifauna. Other common species averaging between 5 and 20 individuals per month included canvasback duck (*Aythya valisineria*), limpkin (*Aramus quarauna*), pied-billed grebe (*Podilymbus podiceps*), great blue heron (*Ardea herodias*), green heron (*Butorides vivescens*), least bittern (*Ixobrychus exilis*), and fish crow (*Corvus ossifragus*).

Year II - 1977-1978 (poststocking). Forty-one species of waterfowl and wading birds were observed with a mean of 1,015 individuals per month. Average number per month was considerably lower than the baseline year. November through February produced the largest numbers due to the influx of migratory waterfowl, with American coots, ring-necked ducks, and ring-billed gulls the most numerous species observed during this period. Fewer species of migratory waterfowl were observed as compared to Year I. Principal wading birds present were great blue heron, green heron, great egret (*Casmerodius albus*), and Louisiana heron (*Egretta tricolor*).

Year III - 1978-1979 (poststocking). Fewer species of waterfowl and wading birds were observed on Lake Conway. The number of species declined by 30 percent, dropping from 41 species in 1977-1978 to 29 species for the year 1978-1979. The average number of birds per observation decreased by 20 percent in 1978-1979. Average number of birds per observation decreased to 908 during Year III. The winter quarter again had the greatest influx of birds; this quarter's survey revealed 1,385 birds. Ring-necked ducks totaled only 221 specimens in the winter quarter. The most predominant species observed was mallard duck, with a total of 152.25 per observation.

The winters of Year I and Year II were milder than the winter of Year III. Milder winters most likely caused fewer waterfowl to overwinter on Lake Conway. Urbanization (shoreline development) is a probable cause for the reduction of wading birds.

Waterfowl food habits

Year II - 1977-1978 (poststocking). Gizzards from four species of waterfowl revealed ten plant species and nine animal taxa. Leaves and stems of hydrilla and Illinois pondweed were the most commonly encountered food items, with hydrilla accounting for 14 percent by volume of all gizzards examined. *Nitella* oogonia were found in 23 percent of the specimens, but constituted a small volume. Mallards and Florida ducks fed heavily on seeds, principally Illinois pondweed and wax myrtle (*Myrica cerifera*) seeds. Ring-necked ducks consumed primarily *Nitella* oogonia, with Illinois pondweed seeds the second most abundant food item.

Year III - 1978-1979 (poststocking). Cattail (*Typha latifolia*) seeds and Illinois pondweed leaves were noted in 46 percent of coot gizzards examined this year. Cattail seeds ranged from 20 to 200 per gizzard when present. Other vegetation noted was waterhyacinth

(*Eichhornia crassipes*) leaves and roots. Insect remains were found in two gizzards.

Illinois pondweed was preferred by ring-necked duck with 75 percent of the gizzards containing at least one piece of a plant. One gizzard contained a small amount of hydrilla. Total animal matter consisted of six snails (*Physidae*) and 1 ml of crushed clam shells.

Illinois pondweed was one of the most preferred food items of waterfowl in both years. Illinois pondweed proved to be an important food item in both years. Hydrilla was important in the first year, but quantity consumed during the second year was drastically reduced. The reduction in consumption of hydrilla may be due to the reduction of the plants in the lake.

Aquatic Mammals Results

Sampling results

Year I - 1976-1977 (prestocking). Aquatic-oriented mammals observed in, or adjacent to, Lake Conway included opossum (*Didelphis marsupialis*), raccoon (*Procyon lotor*), river otter (*Luttra canadensis*), Florida water rat (*Neofiber alleni*), and marsh rabbit (*Sylvilagus palustris*). Three hispid cotton rats (*Sigmodon hispidus*) were the only mammals captured during the week of 7-11 March 1977.

Year II - 1977-1978 (poststocking). Sherman traps captured primarily hispid cotton rats, but success was quite low (0 to 15 percent). Three rice rats (*Oryzomys palustris*) were also taken. Racoons and opossums were the principal larger mammal species present. Forty-seven traps set for Florida water rats produced nine animals, with success per site varying from 0 to 60 percent.

Numbers of Florida water rat houses observed were quite variable, ranging from 39 in January at the west pool site to 0 in March at all locations. Maidencane and pickerelweed were the preferred plants for constructing houses, although other plants were used when these plants were absent.

Year III - 1978-1979 (poststocking). Loss of two sites due to urbanization greatly curtailed sampling of aquatic mammals. Again, numbers of houses varied greatly with extremes in water levels. Winter and spring trapping produced 26 hispid cotton rats, 8 opossums, 3 rice rats, 4 raccoons, 1 marsh rabbit, 1 river otter, and 1 Florida water rat.

Florida water rat nests ranged from 12 in the spring quarter at the west pool site to 0 for the same site in the fall quarter. Water levels were normal for the spring quarter and extremely low during the fall quarter. The most sought after plants for house construction were again maidencane and pickerelweed.

Loss of aquatic mammals was primarily due to urbanization. If the loss of shoreline is continued, aquatic mammals will have to seek other locations.

Summary

The apparent reduction of Illinois pondweed and hydrilla has had no definitive effect on fish populations during the three study years. Continued loss of Illinois pondweed could cause a shift from littoral zone fish to pelagic species. Loss of this plant and hydrilla (important food items for migratory birds) could also mean a decline in overwintering waterfowl. Continued feeding by grass carp on Illinois pondweed could possibly cause complete elimination of this plant. Currently, urbanization has had the greatest effect on aquatic mammals.

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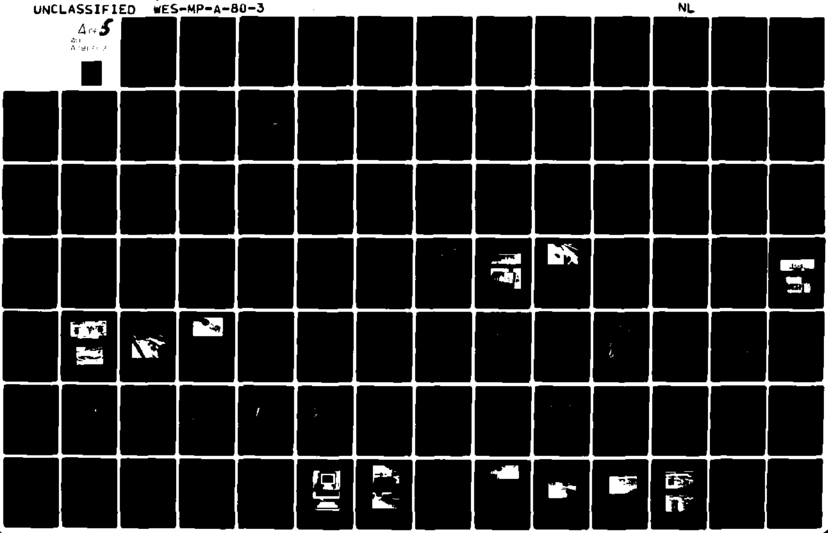

LARGE-SCALE OPERATIONS MANAGEMENT TEST USING THE WHITE AMUR AT LAKE CONWAY, FLORIDA

Water Quality

by

R. T. Kaleel*

Introduction

The mission of the Orange County Pollution Control Department in the Lake Conway LSOMT has been to document prestocking or baseline water quality characteristics and subsequent changes occurring since the stocking of the white amur. Additionally, the chemical and physical analyses of benthic sediments and aquatic macrophytes were undertaken.

Operating Procedures

To accomplish this, monthly water samples were obtained from near-surface, middepth, and/or near-bottom levels in the water column at 11 selected stations (Figure 1). Also, quarterly samples were obtained from stations located near the center of the respective pools. This sampling schedule was changed during the second poststocking period whereby some of the selected stations were sampled every other month. Table 1 lists the parameters that were selected to document water quality as well as the chemical and physical characteristics of benthic sediments and aquatic macrophytes. All water quality analyses were performed according to the procedures outlined in Standard Methods,** or were performed in accordance with procedures mutually agreed to by the Orange County Pollution Control Department and WES.

Prestocking Data Analysis

The prestocking or baseline time frame began in January 1976 and extended through August 1977. Table 2 illustrates the mean concentrations and standard deviations of several parameters recorded for Lake

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* Orange County Pollution Control Department, Orlando, Florida.
** American Public Health Association. 1971. Standard Methods for the Examination of Water and Wastewater. 13th ed.

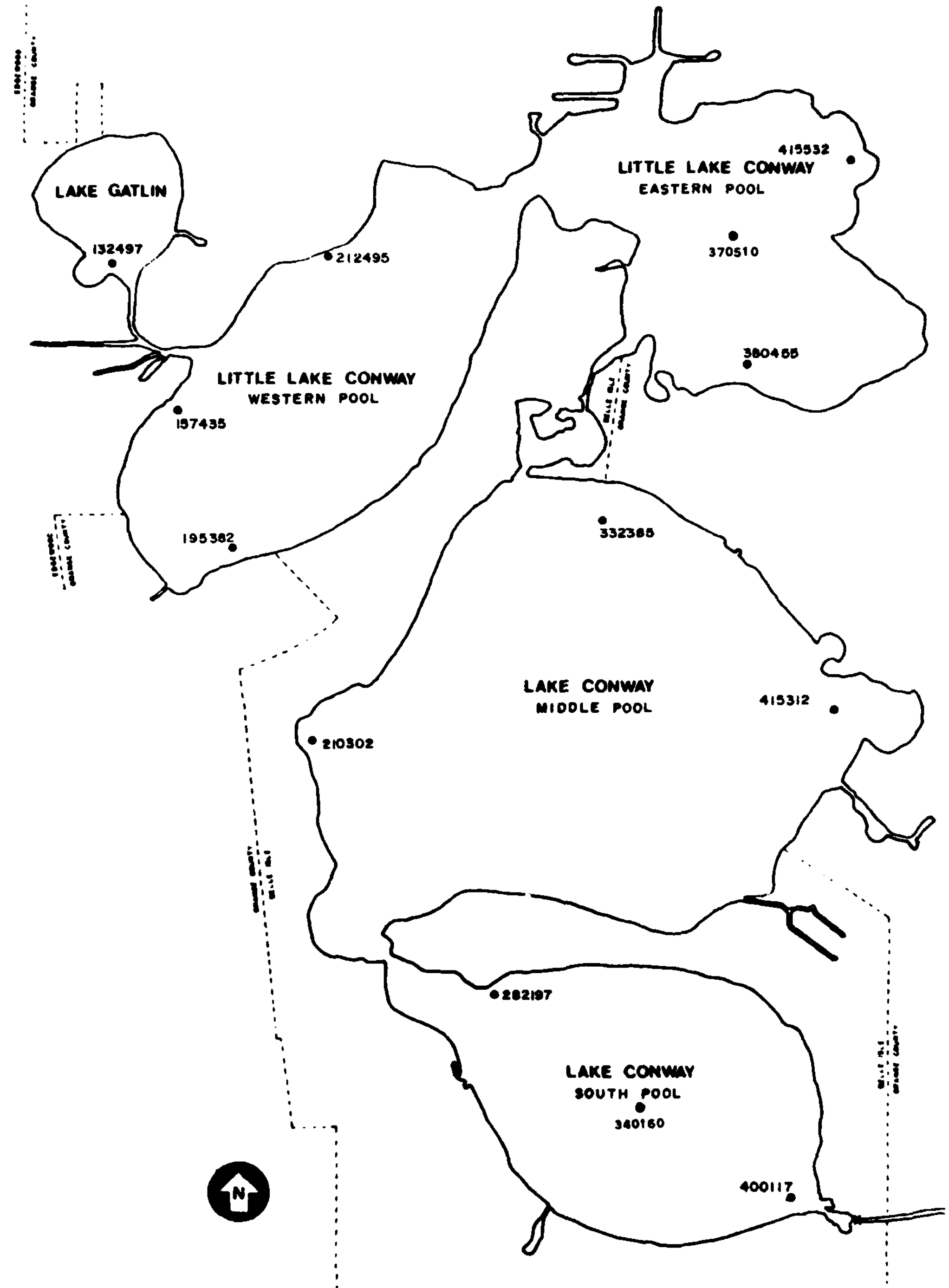

Figure 1. LSOMT sampling station locations

Table 1

Water Quality Parameters

Chemical and Biological Analysis	
Dissolved oxygen (DO)	Solids, volatile
Biochemical oxygen demand (BOD)	Turbidity
Chemical oxygen demand (COD)	Sodium
Hardness	Calcium
pH	Magnesium
Alkalinity	Potassium
Acidity	Iron
Phosphorus, total	Copper
Phosphorus, ortho	Lead
Phosphorus, total unfilterable	Chlorophyll *a*
Nitrate-nitrite	Chlorophyll *b*
Ammonia	Chlorophyll *c*
Organic nitrogen	Ratio, chlorophyll *b*:*a*
Chlorides	Functional, chlorophyll *a*
Solids, total	Nonfunctional, chlorophyll *a*
Solids, suspended	Carotenoids, nonastacins
In Situ Measurements	
Temperature	Oxidation reduction potential
Specific conductance	Dissolved oxygen
Secchi disc	Primary productivity
pH	

Table 2

Baseline Data Comparison

Parameter	132497 Lake Gatlin Mean Value	132497 Lake Gatlin Standard Deviation	400117 South Pool Mean Value	400117 South Pool Standard Deviation
Temperature	23.6°C	5.7°C	23.2°C	5.8°C
Conductivity	270 umho/cm	12 umho/cm	210 umho/cm	12 umho/cm
Alkalinity	40 mg/ℓ	3.6 mg/ℓ	32 mg/ℓ	1.4 mg/ℓ
Hardness	82 mg/ℓ	4.8 mg/ℓ	60 mg/ℓ	5.8 mg/ℓ
Calcium	14 mg/ℓ	1.8 mg/ℓ	13 mg/ℓ	1.8 mg/ℓ
Sodium	16 mg/ℓ	2.5 mg/ℓ	15 mg/ℓ	0.9 mg/ℓ
Potassium	5.3 mg/ℓ	0.3 mg/ℓ	4.0 mg/ℓ	0.3 mg/ℓ
Magnesium	11.0 mg/ℓ	0.7 mg/ℓ	6.5 mg/ℓ	0.4 mg/ℓ
Secchi disc	2.1 m	0.7 m	2.9 m	0.7 m
Organic nitrogen	0.56 mg/ℓ	0.13 mg/ℓ	0.49 mg/ℓ	0.07 mg/ℓ
BOD	1.3 mg/ℓ	0.5 mg/ℓ	1.1 mg/ℓ	0.4 mg/ℓ
COD	15 mg/ℓ	5 mg/ℓ	16 mg/ℓ	4 mg/ℓ
Total solids	170 mg/ℓ	16 mg/ℓ	130 mg/ℓ	6 mg/ℓ
Total phosphorus (filtered)	0.018 mg/ℓ	0.006 mg/ℓ	0.017 mg/ℓ	0.007 mg/ℓ
Total phosphorus (unfiltered)	0.028 mg/ℓ	0.009 mg/ℓ	0.025 mg/ℓ	0.009 mg/ℓ
Volatile suspended solids	2.5 mg/ℓ	1.8 mg/ℓ	1.7 mg/ℓ	1.2 mg/ℓ
Carotenoids	6.5 mg/m^3	4.8 mg/m^3	3.1 mg/m^3	2.8 mg/m^3

Gatlin and a sampling station in the south pool. These data more or less represent the extremes documented during the baseline study. Specific conductance, hardness, and total solids data show that Lake Gatlin is more highly mineralized than the south pool. Considering all data compiled for total filterable phosphorus, total unfiltered phosphorus, and organic nitrogen, all concentrations fell within one standard deviation of the respective means calculated for the baseline study. Nitrate-nitrite, ammonia, orthophosphorus, and copper were seldom measured in concentrations greater than their respective detection limits. Iron and lead concentrations were only reported at the detection limits during the baseline study. Figure 2 illustrates the general trend of decreasing mineralization from Lake Gatlin downstream through the various pools. Likewise, Figure 3 shows that chlorophyll a levels followed a similar pattern--the phytoplankton community declined from Lake Gatlin downstream to the south pool.

Parameters found to vary seasonally included organic nitrogen, total filterable phosphorus, dissolved oxygen, chlorophyll a, and carotenoids. Figure 4 illustrates a summer and fall maximum of organic nitrogen and chlorophyll a and a concomitant minimum of total filterable phosphorus. The reverse trend occurs in the winter and spring--a maximum of total filterable phosphorus occurs with a corresponding minimum of organic nitrogen and chlorophyll a concentrations. Similar seasonal trends were noted in each of the respective pools during the baseline period.

Another factor that was documented during the baseline study was the tendency of the various pools to stratify during the warmer months. Table 3 shows that an extreme stratification was occurring at the station along the west shore of the west pool, and a less severe stratification occurred in the east and south pools. While stratification is an important determinant in the vertical distribution of various parameters occurring in the water column, statistically, dissolved oxygen, pH, turbidity, and chlorophyll a were found to vary significantly with sampling depth.

Table 3

Stratification Data

West Pool (157435) 8-25-76			East Pool (370510) 9-30-76			South Pool (340160) 6-24-76		
Depth m	Temp °C	DO mg/ℓ	Depth m	Temp °C	DO mg/ℓ	Depth m	Temp °C	DO mg/ℓ
N.S.	27.5	7.6	N.S.	28.5	8.2	N.S.	27.0	8.1
3.7	27.5	7.4	3.2	28.5	6.7	4.3	27.0	7.9
7.0	23.5	0.1	6.0	27.5	0.2	8.5	26.0	0.2

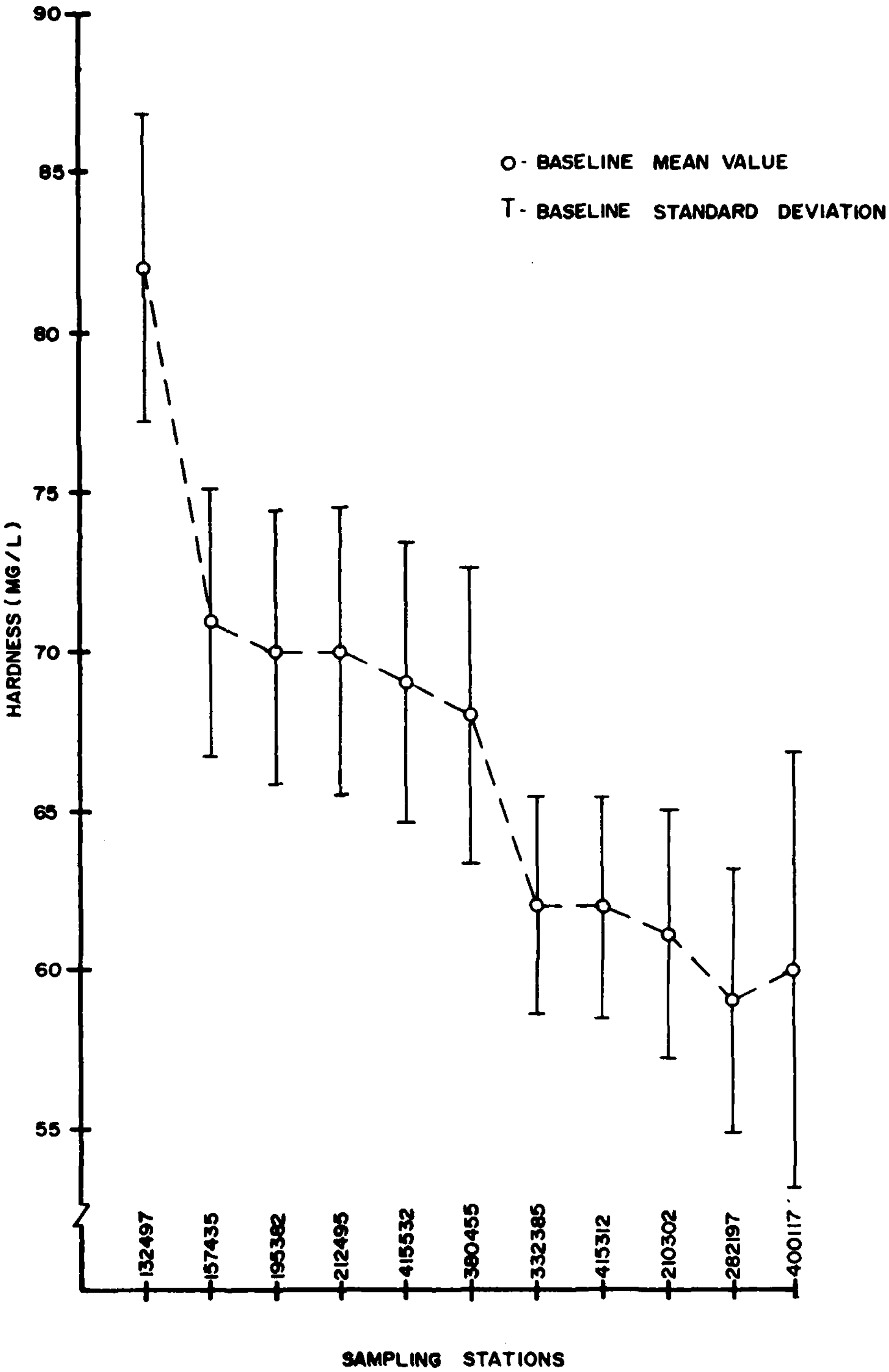

Figure 2. Trends in hardness concentrations

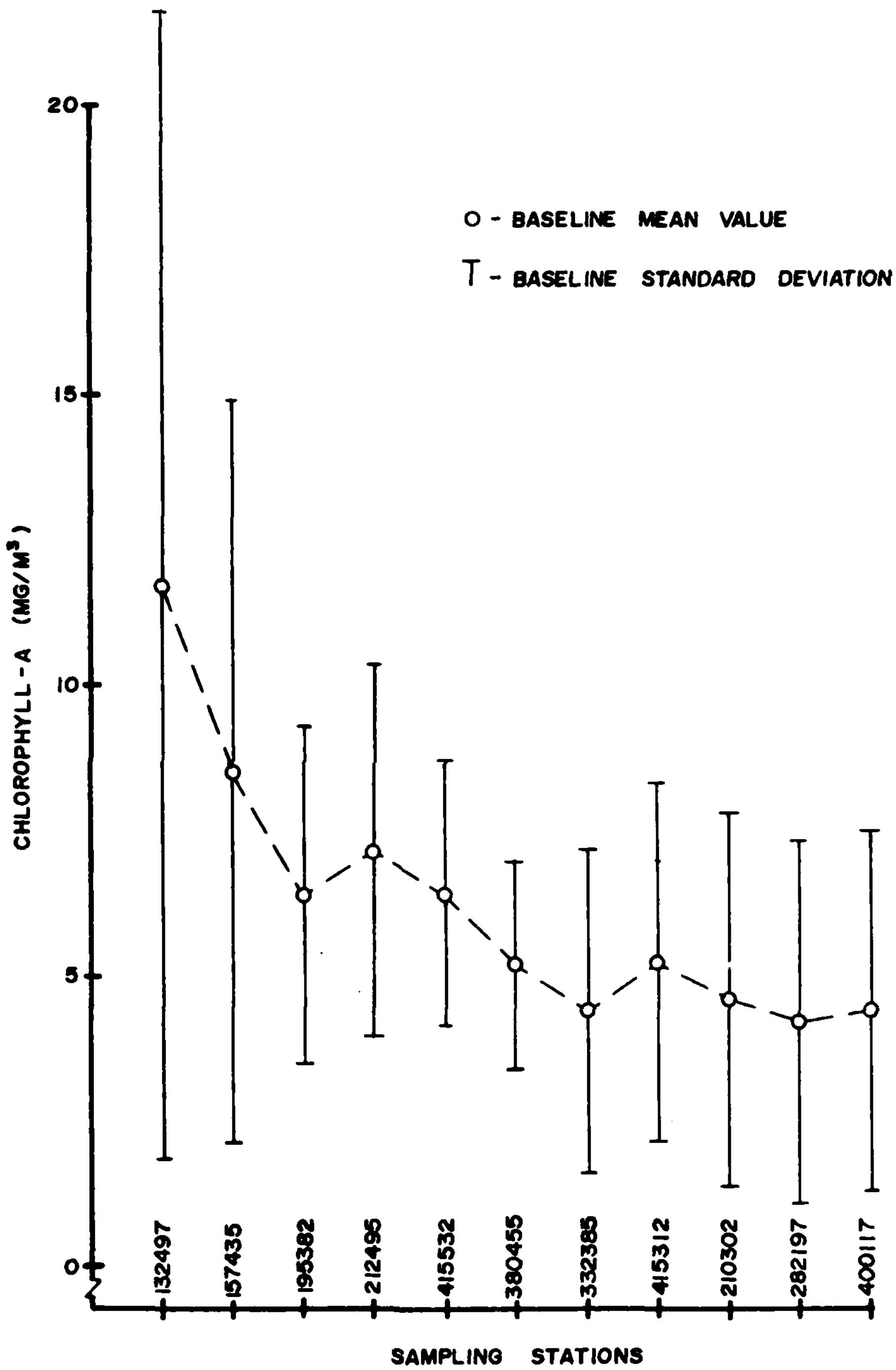

Figure 3. Trends in chlorophyll a concentrations

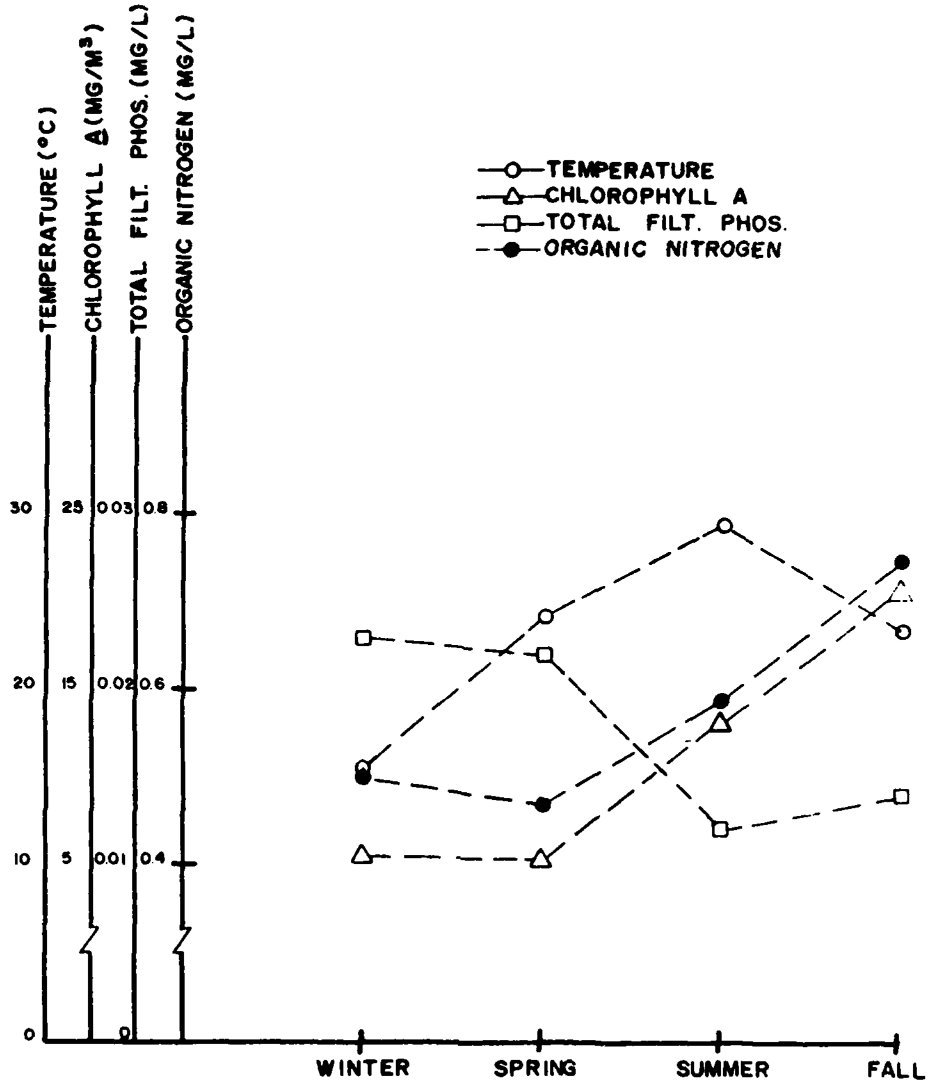

Figure 4. Correlation of selected parameters for sampling station 132497, Lake Gatlin

Thus, baseline studies documented spatial and temporal trends with regards to water quality. Also, other limnological factors were identified and documented that influence water quality.

Poststocking Data Analysis

September 1977-August 1978

The first poststocking time period began in September 1977 and

extended through August 1978. Table 4 gives a comparison between adjusted baseline and poststocking mean concentrations. The adjustment in the baseline data was necessary because of seasonal bias that resulted from comparisons of the 20-month baseline time frame versus the 12-month poststocking time frame. Volatile suspended solids, biochemical oxygen demand, turbidity, and total filterable and total unfiltered phosphorus decreased in concentration. Mean organic nitrogen, chlorophyll a, and carotenoid concentrations were relatively unchanged by comparison.

Water quality parameters previously reported at concentrations less than their respective limits of detection followed a similar pattern for this poststocking period. However, copper, nitrate, and ammonia measurements exceeded detection limits on several occasions. Also, during this first poststocking period, the trend of decreasing mineralization from Lake Gatlin downstream through the various pools changed somewhat. Figure 5 shows that the mean values for hardness were very similar in all pools--the means ranged from 61 to 65 mg/ℓ for all stations, except for Lake Gatlin. Figure 6 illustrates that the distribution of chlorophyll a followed a similar spatial pattern as that of hardness.

In summary, a trend developed in which all pools exhibited similar concentrations of water quality parameters, with the exception of Lake Gatlin. Also, mean concentrations of phosphorus decreased at all stations, while copper, nitrate, and ammonia were occasionally detected in the water column at most stations.

September 1978-August 1979

The second poststocking time frame began in September 1978 and extended through August 1979. Table 4 also gives a comparison of data collected during the second poststocking time period. Comparing the mean values, four of the nine parameters decreased in concentration when compared to the baseline data. Net decreases were noted for total filterable phosphorus, total unfiltered phosphorus, BOD, and volatile suspended solids. Organic nitrogen values remained relatively unchanged on a percentage basis compared to the baseline period. Potential significant percentage increases were noted for ammonia nitrogen, COD, chlorophyll a, and carotenoids. Statistical tests were performed on the parameters identified as having potentially significant changes in concentration levels. At the 95 percent confidence level, only ammonia nitrogen and total unfiltered phosphorus exhibited significant change. Both of these parameters showed significant change at the 99 percent level of confidence. Only at the 99.9 percent level of confidence did changes in the concentrations of these parameters become insignificant.

Several of the water quality parameters previously reported as nondetectable ceased to conform to this pattern. Nitrate-nitrite nitrogen was observed in measurable concentrations as the result of a decrease in the detection level for this parameter. However, ammonia nitrogen was previously only occasionally measured in amounts exceeding the minimum detectable level. During this poststocking period, this

Table 4

Comparison of Prestocking and Poststocking Data

Parameter	Baseline Mean Value	Adjusted Baseline Mean Value	Poststocking I Mean Value	Net Change, %	Poststocking II Mean Value	Net Change, %
Total filtered phosphorus	0.017	0.0165	0.012	-24	0.010 mg/ℓ	-39
Total unfiltered phosphorus	0.025	0.025	0.016	-36	0.015 mg/ℓ	-40
Organic nitrogen	0.50	0.515	0.50	-3	0.53 mg/ℓ	+5
Carotenoids	4.2	3.1	3.3	+6	4.4 mg/m^3	+30
Volatile suspended solids	1.8	1.8	1.2	-33	1.6 mg/ℓ	-11
BOD	1.3	1.4	0.9	-36	1.2 mg/ℓ	-7
COD	1.5	1.6	1.3	-19	20 mg/ℓ	+25
Chlorophyll *a*	6.3	5.5	5.9	+7	6.4 mg/m^3	+14
Ammonia nitrogen					0.09 mg/ℓ	+44

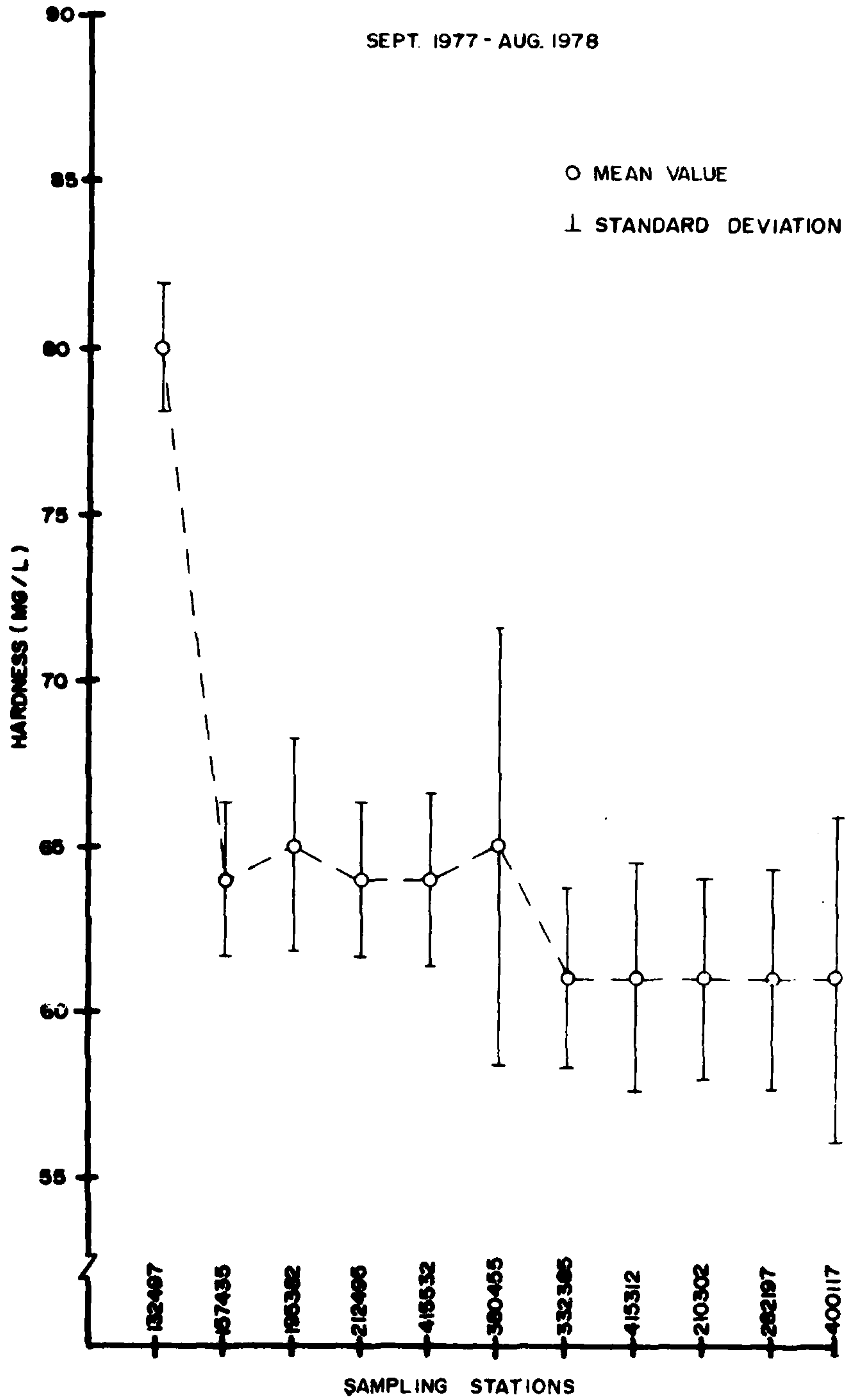

Figure 5. Trends in hardness concentrations

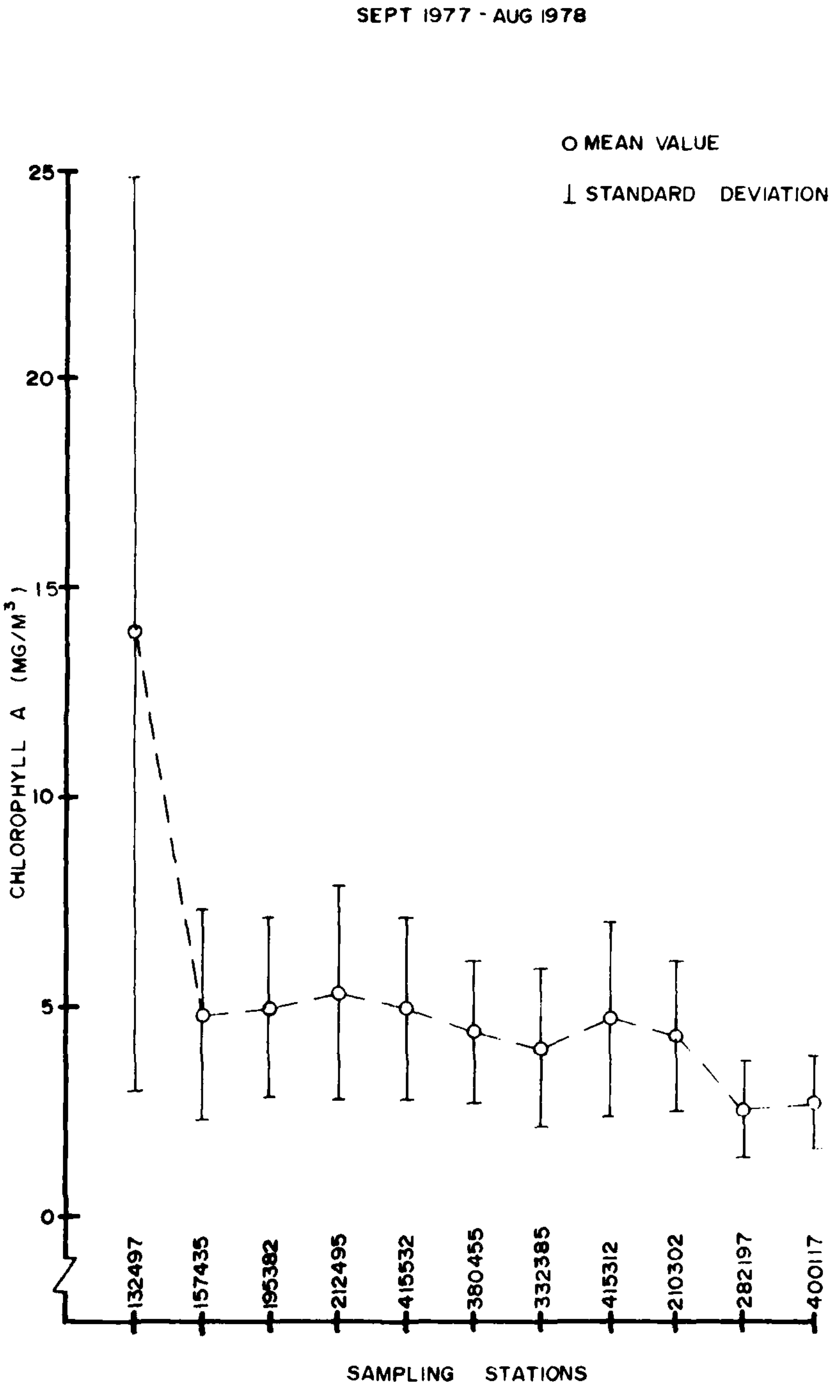

Figure 6. Trends in chlorophyll a concentrations

parameter was found to exceed the detection limits at all 11 sampling stations. Total filterable phosphorus concentrations were consistently observed to be present in amounts less than the detectable level. Other minor changes were noted concerning the frequency in which detectable values occurred.

In summary, the baseline report noted a trend of decreasing mineralization proceeding from Lake Gatlin to the south pool of Lake Conway. This trend appeared to change during the first poststocking period in that the south, middle, eastern, and western pools developed a tendency toward similar water quality conditions. This change appears to have continued during the second 12-month poststocking period.

Conclusions

Statistical analyses show that the changes in water quality that occurred during this second poststocking period were insignificant, with the exception of phosphorus and ammonia nitrogen concentrations. The potential trends that were noted during this sampling period are summarized as follows:

- a. Filterable and unfilterable phosphorus concentrations are decreasing significantly.
- b. Ammonia nitrogen concentrations have increased to levels exceeding the minimum detectable level of this parameter, and the increase that has occurred is statistically significant, albeit the mean concentration is 0.09 mg/ℓ.
- c. COD concentration levels have increased slightly, but not significantly.
- d. Organic nitrogen concentration levels are relatively unchanged.
- e. Carotenoids and chlorophyll a levels are increasing, although not significantly.
- f. Volatile suspended solids and BOD concentration levels have reversed their previous decreasing trend and have reverted to levels greater than the first poststocking period, but less than the baseline period.

LARGE-SCALE OPERATIONS MANAGEMENT TEST USING THE WHITE AMUR AT LAKE CONWAY, FLORIDA

Benthos

by

Thomas L. Crisman* and Floor M. Kooijman*

Introduction

The Department of Environmental Engineering Sciences of the University of Florida has been responsible for monitoring the response of phytoplankton, zooplankton, and benthic invertebrates to white amur introduction into Lake Conway, Florida, as part of the LSOMT conducted by WES. White amur (7000) were added to Lake Conway during September of 1977, but prestocking data collection began in April 1976. This paper presents the initial results of biological analyses for the second poststocking year (September 1978 to September 1979). A detailed report covering this period will be supplied to WES at a later date.

Secchi Disc Transparency

In lake systems such as Lake Conway that are little influenced by inorganic turbidity, water clarity, as measured by a Secchi disc, provides a semiquantitative estimate of algal density in the water column. Secchi transparency in Lake Conway has always been greatest during winter, the period of lowest algal biomass, and least (1.8 to 2.0 m) during summer associated with an expansion of algal populations. With the exception of the absence of a pronounced increase in Secchi transparency during the winter of 1978-1979, no major differences in water clarity were apparent between prestocking and poststocking years. The low winter Secchi transparency during the second poststocking year is attributed to an abnormally high seasonal algal population during this period.

Phytoplankton

Algal density in the water column of Lake Conway (Figure 1) was

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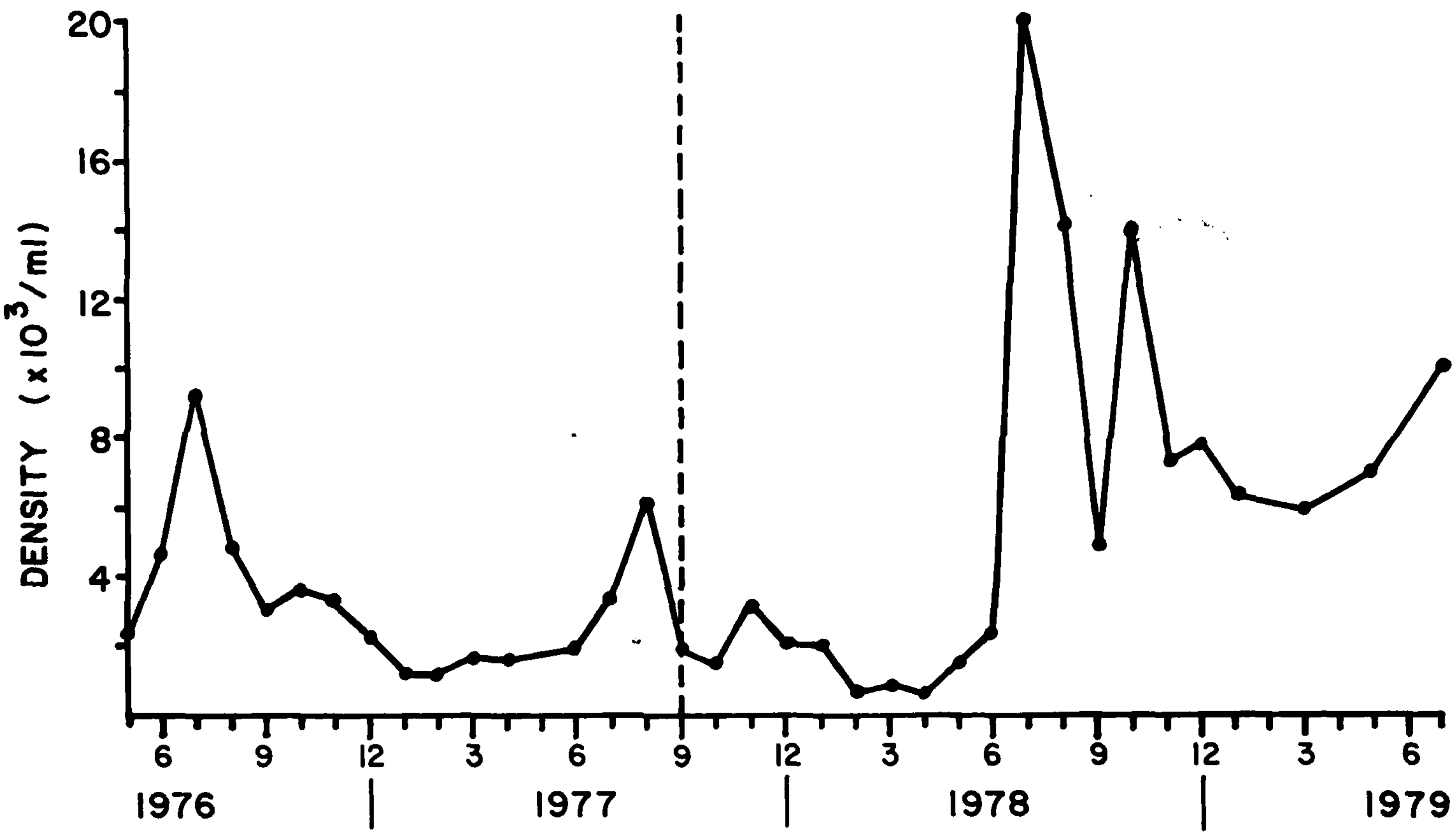

Figure 1. Phytoplankton concentrations in the Middle Pool of Lake Conway both before and after the September 1977 introduction of white amur

generally maximal during summer and minimal during late winter and early spring, thus paralleling seasonal changes in Secchi disc transparency. Algal populations were higher during the summers of both the first and second poststocking years than recorded for the prestocking years, and the 1978-1979 winter algal density was at least double that recorded for a comparable period during previous monitoring.

The importance of blue-green algae generally paralleled seasonal changes in total phytoplankton concentrations. Blue-green algae rarely constituted greater than 60 percent of total phytoplankton individuals in Lake Conway prior to white amur introduction, but following the spring of the first poststocking year (1978), blue-green algae consistently represented greater than 75 percent of total algal abundance (Figure 2). This increased importance of blue-green algae was accompanied by a 30 percent reduction in the total number of phytoplankton species encountered in the lake. Blue-green algae became dominant largely at the expense of diatoms and cryptophytes.

Zooplankton

During the prestocking years, zooplankton populations (Figure 3) were maximal during spring (March-May), fell to minimal levels during summer, and displayed a secondary population peak during fall (September-November). The spring peak during the first poststocking year was extended relative to that of previous years. In addition, the fall population peak during this year was nearly equal to the spring peak, and populations remained high throughout the winter and spring of the second poststocking year. The extended seasonal zooplankton population peaks observed especially during the second poststocking year are attributed to the increased availability of phytoplankton, the principal zooplankton food, during this period.

On an annual basis, the zooplankton assemblage of Lake Conway was dominated by copepods during both the prestocking and poststocking periods. The two major subdominants, cladocerans and rotifers, increased in importance seasonally, but no major difference in their overall importance can be associated with the introduction of white amur.

Benthic Invertebrates

Throughout the Conway study, the density of benthic invertebrates was consistently higher at shallow (less than 4 m) than at deep (greater than 4 m) stations (Figure 4) with maximal numbers appearing generally during winter and minimal numbers during summer. Similarly, the same trends were evident for the number of benthic invertebrate species encountered in the Conway system. Neither the density of individuals nor the number of benthic species differed markedly between the prestocking and poststocking periods.

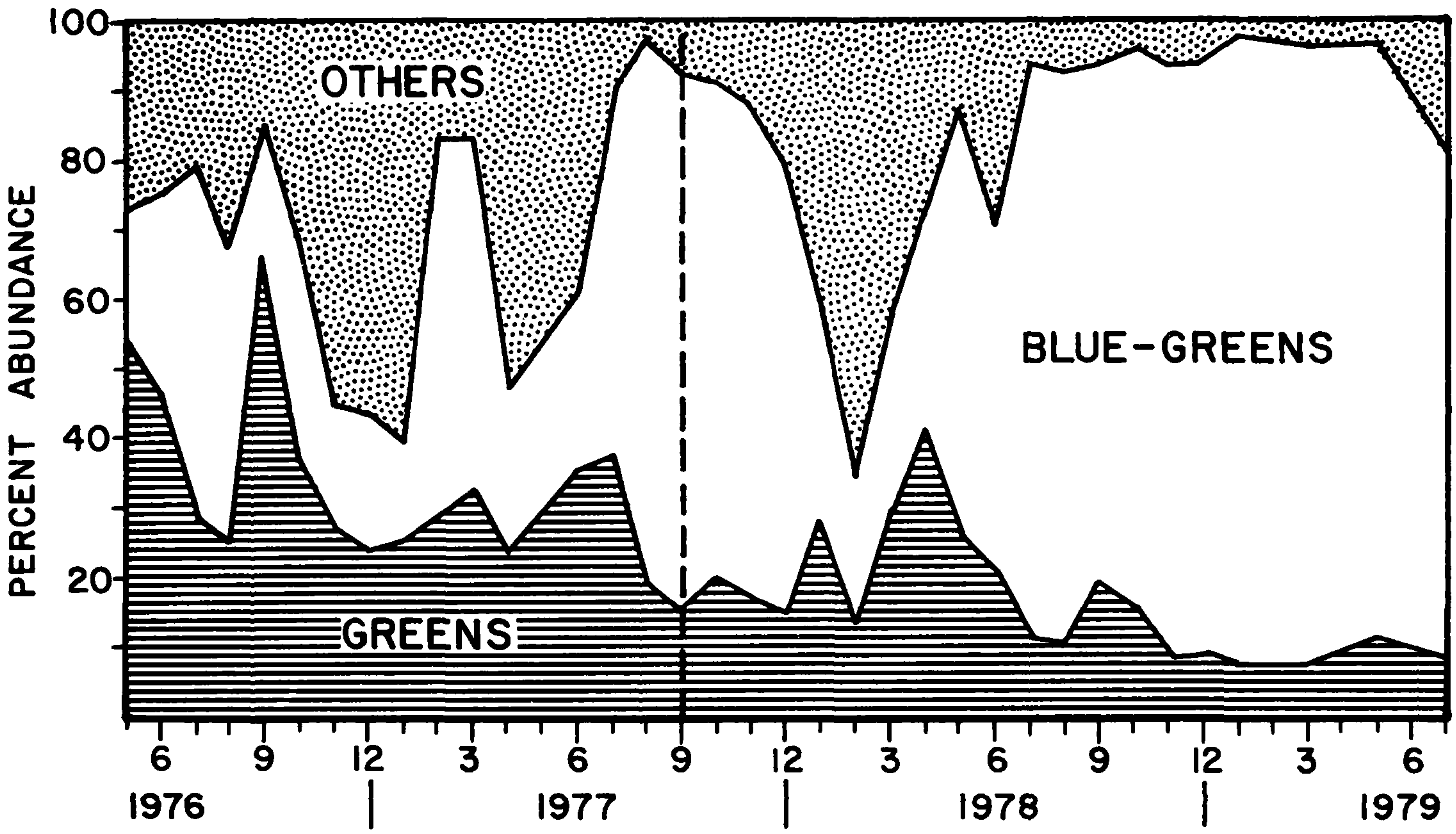

Figure 2. Partitioning of total phytoplankton abundance in the Middle Pool of Lake Conway by principal algal groups both before and after the September 1977 introduction of white amur

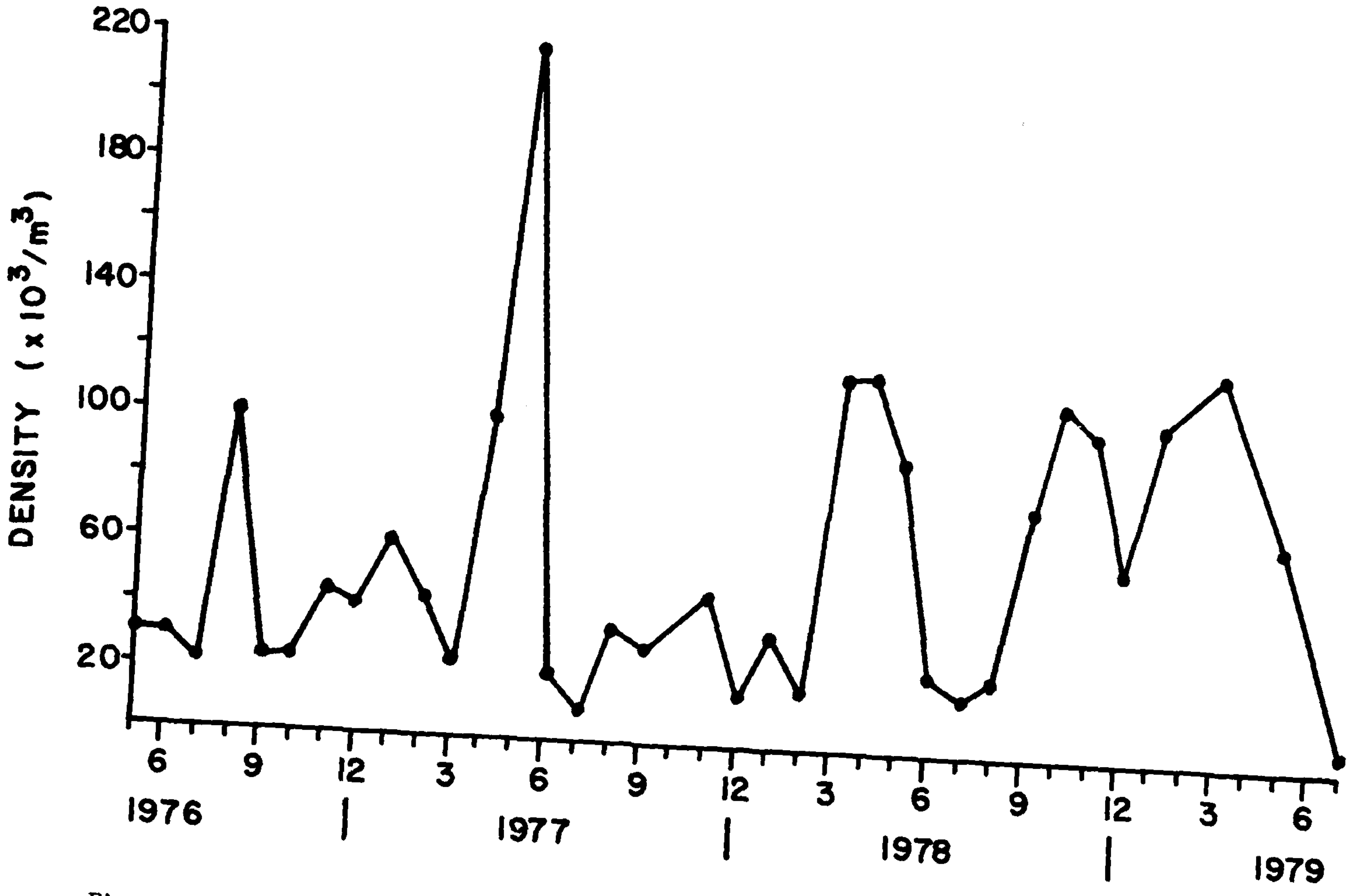

Figure 3. Zooplankton concentrations in the Middle Pool of Lake Conway both before and after the September 1977 introduction of white amur

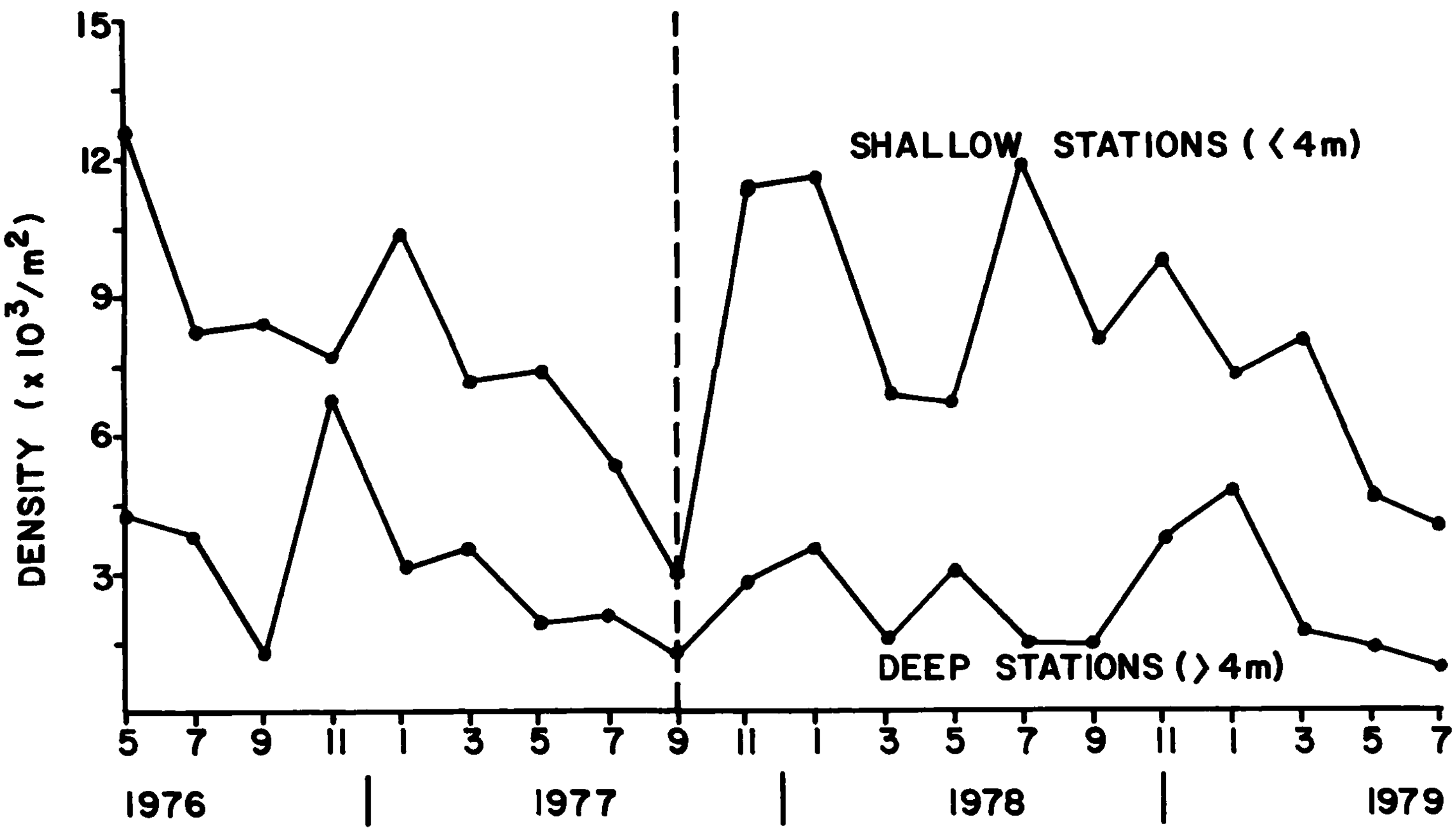

Figure 4. Density of total benthic invertebrates at shallow and deep stations in the Middle Pool of Lake Conway both before and after the September 1977 introduction of white amur

Finally, the relative importance of the major benthic invertebrate groups did not change as a function of white amur introduction. Although minor seasonal differences were noted, shallow stations were dominated throughout the year by oligochaetes and chironomids, while these two groups shared their dominance of the benthic assemblage in deep water with the phantom midge, *Chaoborus*. *Chaoborus* is not entirely benthic in its behavior, but migrates vertically through the water column to feed on zooplankton in the surface waters at night.

Conclusions

Phytoplankton and their principal grazers, zooplankton, have displayed the greatest biotic response to the introduction of white amur into Lake Conway, Florida. Algal concentrations began to increase markedly over prestocking levels 10 months following white amur introduction. Prestocking seasonal patterns are still evident, but populations for any given month are now at least double those of comparable months from the prestocking period. This increase in total algal abundance has been accompanied by increased dominance of blue-green algal species largely at the expense of diatoms, cryptophytes, and green algae. Zooplankton populations also increased in response to increased algal availability; however, unlike the algae, no major shift in zooplankton dominance accompanied white amur introduction.

The biotic response to fish stocking was least pronounced with the benthic invertebrates. Shallow stations (less than 4 m) consistently were characterized by higher benthos densities than deep (greater than 4 m) stations throughout the investigation, but no major population or compositional changes can be associated with white amur introduction. The greater density and diversity of the shallow relative to deep stations are attributed to greater habitat diversity (macrophytes, substrate heterogeneity) and less pronounced oxygen stress at the former stations.

In summary, the plankton (phytoplankton and zooplankton) have increased as a result of the introduction of white amur into Lake Conway, but it is still too early to determine whether the system has reached a new level of biotic stability. It is likely that the plankton biomass increase is only temporary and that plankton biomass will stabilize at a lower level with time.

LARGE-SCALE OPERATIONS MANAGEMENT TEST USING THE WHITE AMUR AT LAKE CONWAY, FLORIDA

Herpetofauna

by

J. S. Godley,* Roy W. McDiarmid,* and G. Thomas Bancroft*

Introduction

The environment of central Florida with its extensive lake habitats provides an ideal setting for intensive field studies of subtropical aquatic ecosystems. With the exception of a few local studies, no detailed, integrative investigations of aquatic community dynamics exist. Thus, the proposal by WES (Addor and Theriot 1977) to investigate the suitability of the white amur *Ctenopharyngodon idella* (herein referred to as grass carp) as a potential biological control agent of hydrilla (*Hydrilla verticillata*) was particularly interesting and timely. Not only did the proposed study include an evaluation of the effectiveness of the grass carp as a weed control agent and its impact, direct or indirect, on the associated biota of the system, but it also provided an opportunity to do the first detailed study of a community of amphibians and reptiles in a large aquatic environment.

Objectives

In June of 1977 a study of the herpetofauna of Lake Conway was initiated with the following objectives:

- a. To determine the species of amphibians and reptiles inhabiting the lake system.
- b. To ascertain the habitat requirements, distribution, ecology, and seasonal activity of these species in the system.
- c. To establish quantitative baseline population data for the more common or otherwise important species in each pool in the system including density by habitat, relative age (size) structure, movements, growth, reproduction, food habits, and related parameters as deemed feasible.
- d. To quantitatively monitor changes in the species composition

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or their population parameters during poststocking periods.

e. To determine whether any changes are the result, directly or indirectly, of the grass carp weed control program.

Because of the ecological and behavioral differences that characterize the amphibian and reptile species of Lake Conway, several different kinds of collecting equipment and techniques were used. A 16-ft jon boat with a 25-hp outboard motor was used in placement and monitoring of funnel traps, conducting alligator counts, and censusing shoreline sites.

Sampling Program

The Lake Conway herpetofaunal sampling program involved long-term mark and recapture studies of certain species and incidental and/or short-term studies of the remaining species. Because of the varied ecologies and life histories of the species, several different measuring and marking procedures were required. These techniques are outlined in the following paragraphs.

Aquatic salamanders

Early in the study no permanent marking technique was available for salamanders of the families *Amphiumidae* and *Sirenidae*, and species either were released unmarked or taken for destructive samples. From September 1977 through July 1978, adults of these salamanders were experimentally tagged with plastic numbered Floy fish tags (Model No. FD-68) similar to those described by Pough (1970). The tags, measuring 4.8 cm in total length and weighing 2.0 g, were inserted through the base of the salamander's tail with the T portion protruding through the opposite side (salamanders lack the pterygial bones of fishes preventing internal anchorage of the T). Specimens were weighed (to 0.1 g), then snout-vent length (SVL = tip of snout to posterior margin of vent) and total length (TL = tip of snout to end of tail) were measured by placing the salamander in a V-shaped, clear plexiglas measuring device. As a secondary means of identification, all bite marks, scars, and deformities of salamanders were recorded beginning in March 1978. After processing, all salamanders were released at the capture site.

Many salamanders that were Floy-tagged, released in the field, and subsequently recaptured had ripped out the tag. Although these animals could be distinguished as a recapture, positive identification of individuals often was not possible and Floy-tagging of salamanders was discontinued. Beginning in August 1978, all *Siren* and *Amphiuma* were cold-branded for 8 to 10 sec on the abdomen with copper wire numbers dipped in liquid nitrogen. These brands were recognizable for at least 1 year in the field and this method was used for salamanders for the remainder of the study.

Aquatic turtles

All species of aquatic turtles in the lake system were monitored. Standard measurements taken were weight (to nearest 0.1 g for turtles < 1000 g; to nearest 10 g for turtles > 5000 g) and carapace length (CL = straight mid-line distance with calipers from anterior-most to posterior-most point of carapace) and plastron length (PL = anterior-most to posterior-most point of plastron) to the nearest millimetre. Throughout the study emydid turtles (*Chrysemys floridana, C. nelsoni, Deirochelys reticularia*) were marked by drilling holes in (adults) or notching (juveniles) the marginal scutes using a numbering system similar to Cagle's (1939). Other species were toe-clipped from July 1977 through December 1977 but marked with numbered Floy fish tags (4.8 cm total length, 2.0 g) beginning in January 1978. The Floy tags were inserted through a hole drilled in a posterior marginal scute of the turtle.

Alligators

American alligators (*Alligator mississippiensis*) were not marked for recapture on Lake Conway because (a) the animals are difficult and dangerous to capture and process, (b) Federal and State permits are required for these procedures, and (c) the alligator population on Lake Conway was found to be small and easily monitored by nocturnal censuses and nest counts.

Larval amphibians

The composition, distribution, and relative density of the tadpole fauna of Lake Conway were estimated for each permanent trapping station at the five littoral zone sites. Initially, five standard sweeps of a dip net were taken before the funnel traps were set at a station. In addition, the number and identity of all tadpoles collected at littoral zone and deepwater trapping sites were recorded. Because dip netting disturbed the vegetation at trapping stations and was less successful at collecting tadpoles than funnel traps, dip netting was discontinued. Beginning in April 1978, all tadpoles collected in traps were staged (Gosner 1960) to obtain population estimates of developmental rates and larval lifespan.

Adult frogs

Frog species were monitored by shoreline censuses, herp-patrols, and funnel traps. Because of their cryptic nature and difficulties in capturing adequate numbers of most species, adult frogs in general were not marked for recapture. Instead, the most effective method of monitoring the frog populations proved to be recording the calling activities of males during herp-patrols. This sampling technique was expanded in December 1978 to include actual counts of calling males per 10-m increments on all permanent shoreline sites.

Snakes

All species of aquatic and semiaquatic snakes on Lake Conway were monitored by diurnal shoreline censuses, herp-patrols, and funnel trapping. All collected snakes were identified, sexed (adults only), weighed and measured, individually marked by clipping the ventral

scales (Brown and Parker 1976), and released at the capture site.

A total of 5,836 individuals representing 11 species of amphibians and 16 species of reptiles were observed or captured on Lake Conway during the 15-month baseline study period. Only species dependent on Lake Conway proper for some portion of their life cycle and therefore potentially affected by the introduction of grass carp were considered. Approximately 93 percent of the sampled herpetofauna was obtained within the first 3,000 specimens and one species thereafter. Based on this sample there are three species of salamanders, eight anurans, one crocodilian, eight turtles, and seven snakes inhabiting the Lake Conway complex. Several other rare species may be present.

The probability of capturing or observing a species varied by sampling method. Of the 27 amphibian and reptile species known from Lake Conway, 23 species were identified on herp-patrols and three (*Deirochelys reticularia, Hyla femoralis, H. squirella*) were known only from herp-patrol activities. No species were taken only in funnel traps during the baseline study period, but this method did account for a sizeable portion (>30 percent) of the observations for *Amphiuma means* (93.5 percent), *Siren lacertina* (57.8 percent), *Knosternon subrubrum* (49.1 percent), *Nerodia cyclopion* (31.1 percent), and most anuran larvae. Three species were known only from shoreline censuses, including a salamander (*Eurycea quadridigitata*) and two snakes (*Regina alleni, Thamnophia sirtalis*). All other species were taken by at least two sampling methods.

Judging from the total cumulative species-number curve for Lake Conway shown in Figure 1 and the total number of observations recorded for each pool, between 70 and 80 percent of the total herpetofaunal species inhabiting each pool has been recorded. South Pool had the greatest total number N of observations (N = 1,429) and the highest number of recorded species (N = 22); West Pool had the lowest total number of observations (888) and recorded species (14). Other pools have intermediate values but the species rank order is not in agreement, perhaps indicating differences in habitat availability, species evenness, and/or sampling error.

The known distribution of herpetofaunal species varied by pool. Of the 27 species presently recorded from the Lake Conway system, 11 occur in all pools. These 11 species account for 94.44 percent of the total observations; none represent less than 1.71 percent of the species total. Among the 16 species not known from all pools, no single species contributes more than 1.35 percent to the species total. Additional observations in poststocking years should more clearly define the distribution of amphibians and reptiles within the Lake Conway system.

Twenty-six species were observed on permanent shoreline sites. One salamander (*Eurycea quadridigitata*), a frog (*Hyla squirella*), three turtles (*Chelydra serpentina, Deirochelys reticularia, Kinosternon bauri*), and four snakes (*Coluber constrictor, Regina alleni, Thamnophis sauritus, T. sirtalis*) were recorded only on these permanent sites. The treefrog *Hyla femoralis* is the only species on Lake Conway not

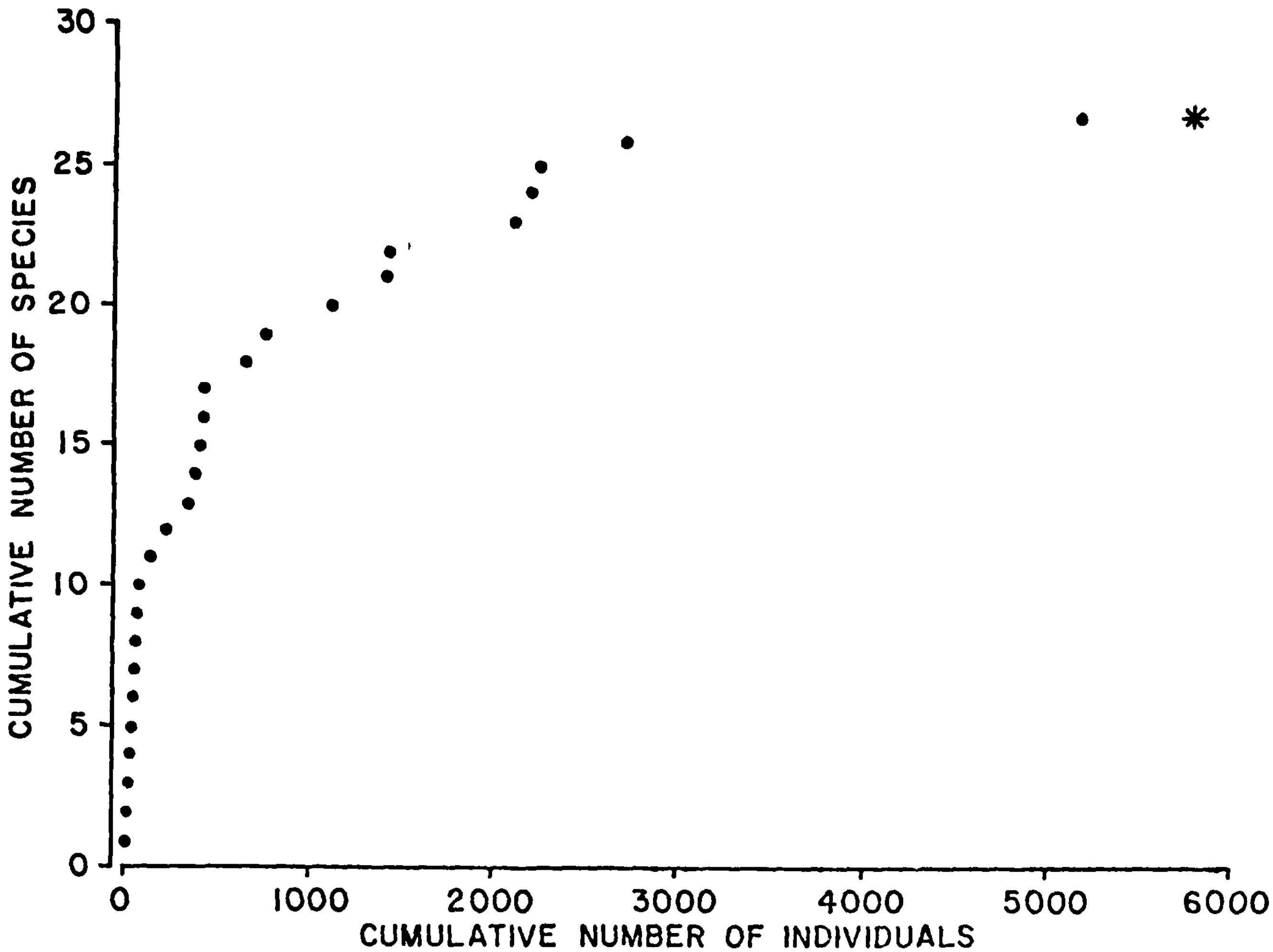

Figure 1. Cumulative number of amphibian and reptile species as a function of the cumulative number of individuals recorded on Lake Conway. Star indicates last individual collected during the baseline study period

known from a permanent shoreline site.

The mean relative densities of 11 species were found to vary significantly between the five permanent shoreline sites during the baseline study period. Funnel trapping showed significant between-site differences in the relative densities of two salamanders (*Amphiuma means, Siren lacertina*), three frogs (*Hyla cinerea* larvae, *Rana grylio* adults and larvae, *R. utricularia larvae*), two turtles (*Kinosternon subrubrum, Sternotherus odoratus*) and a snake (*Nerodia cyclopion*). The mean number of individuals observed or collected per hour on herp-patrols varied significantly in four species including one frog (*Acris gryllus*) and three turtles (*Chrysemys floridana, C. nelsoni, S. odoratus*).

Four species of frogs (*Hyla cinerea, Gastrophryne carolinensis, R. grylio, R. utricularia*) recorded on herp-patrols differ in the mean densities of calling males, but the site means were not significantly different if the entire baseline study period was considered. When only the breeding seasons of these species were analyzed, significant between-site differences in mean densities were obtained for *A. gryllus, H. cinerea, R. grylio,* and *R. utricularia.* Apparently, the large number of tied scores introduced by including the many nights during the nonbreeding season, when no frogs were calling, biased the rank sums tests and significantly reduced the differences between sites.

Community Analyses

Included below are detailed community analyses of the five permanent shoreline sites on Lake Conway.

South Pool

The South Pool permanent shoreline site had the most diverse herpetofauna of any site (19 species), but also received the most sampling effort. The relative density of *Kinosternon subrubrum* was significantly greater on South Pool than on all other sites. The highest total number of observations for 11 other species also was recorded from the South Pool site including two frogs (*Acris gryllus, Hyla squirella*), four turtles (*Chrysemys floridana, Kinosternon bauri, K. subrubrum, Sternotherus odoratus*), and five snakes (*Coluber constrictor, Farancia abacura, Nerodia cyclopion, Regina alleni, Thamnophis sirtalis*). Four of these species (*H. squirella, C. constrictor, R. alleni, T. sirtalis*) were encountered only on the South Pool site during the baseline study period. Thus, many elements of the Lake Conway herpetofauna are best known from South Pool.

During the baseline study the shoreline of the South Pool site was developed gradually for a housing subdivision. Because shoreline development was insidious, changes in herpetofaunal populations are expected to be subtle.

Middle Pool

The Middle Pool site had the second highest number of recorded species (18), but the mean relative density of any one species was not significantly higher or lower than other permanent shoreline sites. Middle Pool was the only site where the salamanders *Amphiuma means* and *Siren lacertina* were equally common (*A. means* was 4.27 times more abundant than *S. lacertina* averaged over all sites). Especially common species were pig frogs (*Rana grylio*) and ribbon snakes (*Thamnophis sauritus*). Of the two female alligators (*Alligator mississippiensis*) known to nest on Lake Conway during the baseline study period, one nested in the marshes of the Middle Pool site and successfully hatched 12 to 16 young in August 1977. The nest site of this female was destroyed in April 1978 and to the best of our knowledge she did not nest on Lake Conway in the summer of 1978.

The Middle Pool site underwent significant changes during the baseline study period. On 26 April 1978 all upland and shoreline vegetation between markers 0 and 120 was cleared with bulldozers and draglines for a housing development but markers 121 to 200 were left intact. To better elucidate changes in the distribution and abundance of the herpetofauna as a result of the perturbation, the analyses that follow were divided into several subsets. All transects were divided into "disturbed" and "undisturbed" sections. In addition, analyses were further subdivided into before and after disturbance categories.

After habitat modification, only 1 individual (a *Rana utricularia* larvae) was collected in 122 trap days on the disturbed section; 12 individuals representing six species were taken in 180 trap days before this section was cleared. On the undisturbed section, 10 individuals of four species were collected in 50 trap days before the adjacent section was cleared; 24 individuals of nine species were recorded in 70 trap days after clearing. These data suggest that (a) clearing of the emergent vegetation severely reduced herpetofaunal populations in the altered areas and (b) surviving individuals may have emigrated to the adjacent, undistrubed habitat.

The spatial distribution of calling frogs also varied as a result of habitat modification. Unfortunately, rigorous recording of the exact locations of calling males did not begin until December 1977; thus, the predisturbance period is underrepresented. However, four frog species called before disturbance, but only two species were recorded from this section thereafter. *Acris gryllus* and *Bufo terrestris* can inhabit and successfully call from shore grass or bare beach environments. However, both *Hyla cinerea* and *Rana grylio* require thick emergent vegetation; these species apparently were extirpated from the disturbed zone.

East Pool

A total of 15 amphibian and reptile species were observed on the East Pool site during the baseline study period. The relative densities of three species (*Amphiuma means*, *Siren lacertina*, *Hyla cinerea*

larvae), as measured by funnel trap success, were significantly higher at East Pool than at all other sites. In addition, East Pool was the only site where the dwarf salamander, *Eurycea quadridigitata*, was found. All of these species were associated with the mats of waterhyacinth (*Eichhornia crassipes*) that dominated much of the site.

In contrast to funnel trapping, the number of nonfrog species observed or collected during herp-patrols on the East Pool site declined through time. This was due primarily to the relatively large numbers of *Sternotherus odoratus* collected on early trips, which were not seen later in the study period.

The temporal distribution of calling frogs on East Pool was similar to that of other sites. Greatest activity for most species occurred from spring through early fall with a peak in late summer. *Rana utricularia* was the only species to call frequently in the winter.

West Pool

The West Pool permanent shoreline site had the lowest number of amphibian and reptilian species (N = 12) recorded for any site. This was caused by an apparently depauperate snake fauna: only one species (*Nerodia cyclopion*) was recorded on the West Pool site but seven were known from the Lake Conway system. Four turtle species (*Chrysemys floridana, C. nelsoni, Sternotherus odoratus, Trionyx ferox*), which were common on most of Lake Conway, were relatively rare on the West Pool site. However, the greatest total number of observations of three frog species (*Hyla cinerea, Gastrophryne carolinensis, Rana utricularia*) were recorded from this site.

Trap stations 0 through 70 were located on beach habitats in several stages of plant succession. These stations produced no captures even though 24.1 percent of the total number of traps set in West Pool during the baseline study period were located in this region. On nonbeach trapping sites, the 14 stations dominated by waterhyacinth produced the greatest proportion of captures, accounting for 61.2 percent of the total captures but only 36.5 percent of the traps set.

As noted for South Pool, the distribution of salamanders and reptiles observed on West Pool herp-patrols appeared to be dependent primarily on off-shore habitat preferences of the component species. *Sternotherus odoratus* was the most commonly encountered species, and over 21 percent of the observations of this species on West Pool were recorded at sites where dense stands of *Potamogeton* occurred in shallow water.

The distribution of all species of calling anurans on the West Pool site appeared clumped. The most abundant species, *Hyla cinerea*, requires erect vegetation for calling sites. It called primarily from four areas containing dense stands of *Pontederia lanceolata* or *Typha latifolia*. The second most common frog, *Gastrophryne carolinensis*, vocalized most frequently from grass clumps along four sections of the West Pool site.

Gatlin Canal

For a disturbed man-made habitat, the Gatlin Canal site contained a surprisingly high number of species (N = 14). This may be because of the diverse array of microhabitats within the canal and/or because of the accessibility of the two other major, alternate habitats (West Pool and Lake Gatlin). Gatlin Canal was the only site where all species of aquatic turtles were known to occur, and the relative density of three species (*Chrysemys floridana, C. nelsoni, Sternotherus odoratus*) was relatively high. However, for the effort expended at the Gatlin Canal site, the diversity and abundance of snake species was low, probably because of the proximity of development and the tendency for land owners to kill most snakes.

Slightly more individuals (54.2 percent of 387 total observations) were sighted on the east side of Gatlin Canal than on the west side. *Sternotherus odoratus* was the most common reptile at this site. The largest concentration of stinkpots occurred near the entrance of Gatlin Canal into West Pool, where a large patch of *Nuphar luteum* was established. The species also was common along the shore opposite the *Nuphar* bed, which was bordered by *Paspalum* sp. and beach habitat. Other areas in Gatlin Canal also produced large numbers of stinkpots but the association of the turtle with specific habitats was not obvious.

Compared with other sites, relatively few frogs were heard calling in Gatlin Canal, but their spatial distribution was patchy. For example, the southern toad, *Bufo terrestris*, called only from beach habitats or where the grass was mowed to the water's edge. *Hyla cinerea* was heard calling mostly from stands of *Pontederia lanceolata* or *Typha latifolia*.

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LARGE-SCALE OPERATIONS MANAGEMENT TEST USING THE WHITE AMUR AT LAKE CONWAY, FLORIDA

Ecosystem Modeling of the Effects of White Amur Grazing on Energy Flows

by

Katherine Carter Ewel* and Thomas D. Fontaine, III**

Introduction

A model that incorporates both carbon and phosphorus flows is being formulated in order to predict the effects of white amur on ecosystem structure and function in Lake Conway, Florida. The major organic matter storages and pathways (Figure 1) include three producer groups: phytoplankton; macrophytes and epiphytic algae, which appear to have a mutualistic relationship with one another; and epipelic (benthic) algae, which grow on the sediments and around the stems of macrophytes.

Feeding relationships derived from the literature indicate that zooplankton feed most heavily on phytoplankton, and benthic invertebrates depend primarily on epipelic algae; both groups obtain 10 to 20 percent of their food from dead organic matter. Three categories of fish are distinguished: herbivorous fish, such as gizzard shad, which feed from a variety of sources but most heavily from epiphytic algae; primary predator fish, such as bluegill, which depend primarily on benthic invertebrates; and secondary predator fish, such as bass, which prey mainly on other fish. Because feeding habits of young predatory fish are more similar to those of herbivorous fish, young primary and secondary predator fish have each been separated from the adults.

Phosphorus flows in the model generally parallel carbon flows with one major exception: each of the three producer groups derives its phosphorus from a different source (Figure 2). Phytoplankton take up phosphorus from the epilimnion and release it through leaching and respiratory processes. Some phosphorus is transported to the sediments as cell death occurs and dead organic matter sinks to the bottom. Macrophytes, on the other hand, obtain phosphorus from sediments, releasing it to the epilimnion as leaching, respiration, and in situ microbial decomposition occur. A substantial proportion is cycled back to the sediments as leaves are sloughed off both during and at the end of the growing season. Epipelic algae apparently also take up phosphorus

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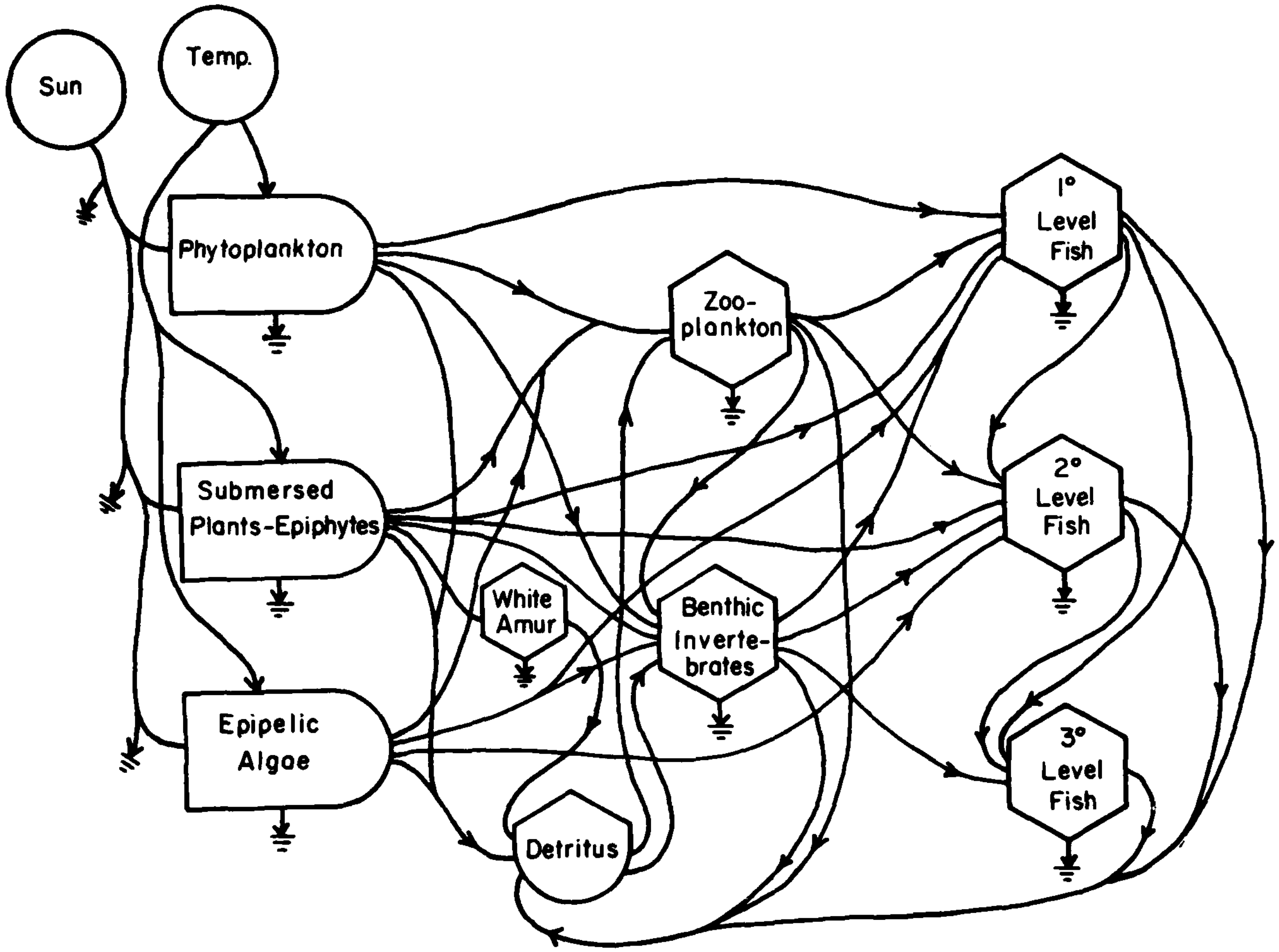

Figure 1. Major organic matter storages and pathways in the Lake Conway model

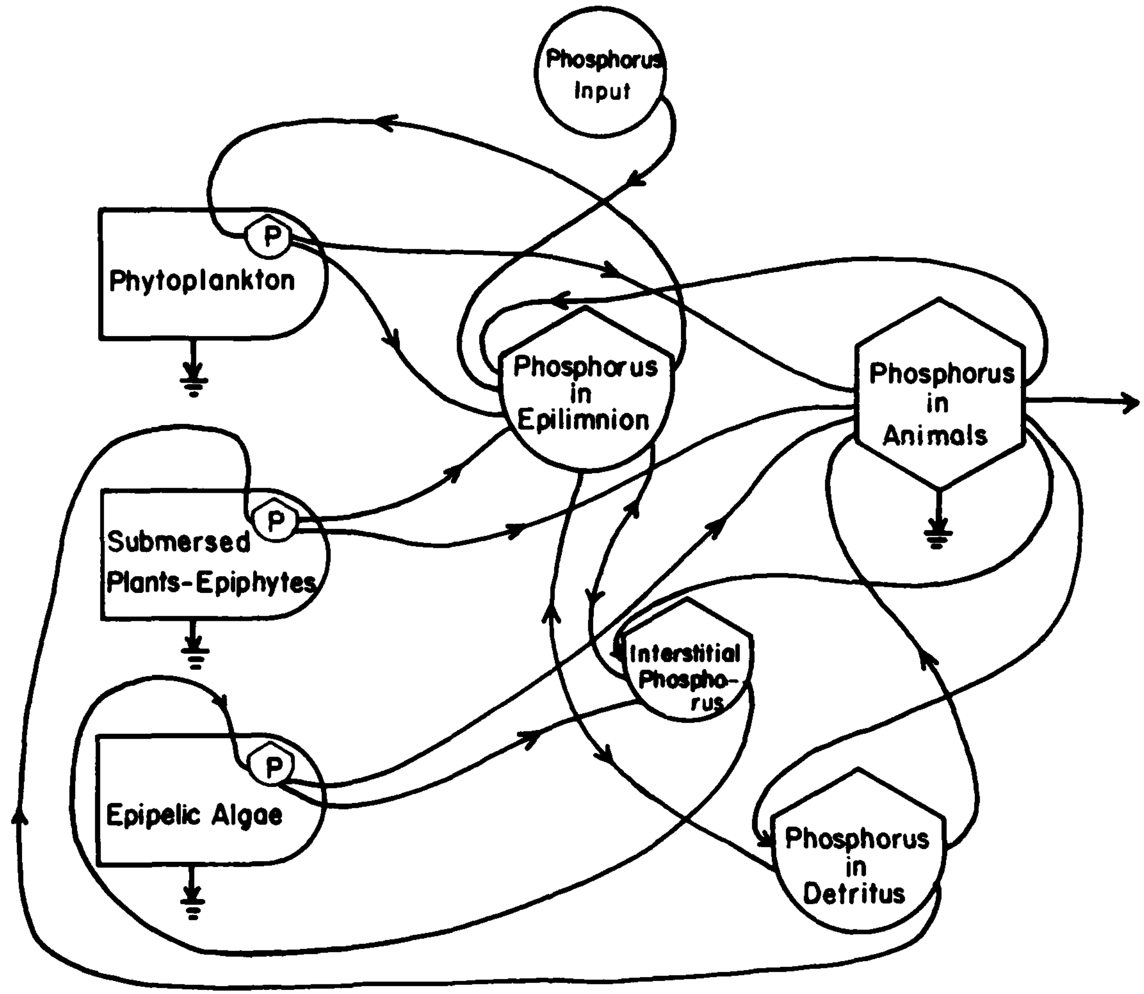

Figure 2. Major phosphorus storages and flows in the Lake Conway model

from interstitial water in the sediments, but do not release much phosphorus into the epilimnion.

During the summer, the hypolimnion in Lake Conway becomes anaerobic. At this time, the simulated hypolimnion becomes continuous with the interstitial water. Fall turnover and isothermal conditions throughout the water column in the winter allow exchange between phosphorus storages in the hypolimnion and epilimnion in both the model and reality.

Baseline data for simulating this model were obtained from other teams on the Lake Conway project; productivity data obtained from monthly measurements of changes in oxygen levels in open water and light-and-dark bottles are reported in Table 1.

Energy Flows in Lake Conway

Macrophytes and algae contribute nearly equally to gross primary productivity in Lake Conway (Table 1), although it should be noted that neither productivity nor biomass of epipelic algae was measured directly, and had to be estimated. In Lake Conway, an estimated 70 percent of the net primary production is grazed; the rest becomes dead organic matter and is either consumed by detritivores or accumulates on the lake bottom as sediment. The lake ecosystem therefore appears to be dominated by a grazing food chain, although the primary grazers--zooplankton and benthic invertebrates--also consume substantial amounts of dead organic matter.

The major role of the macrophytes in the Lake Conway ecosystem appears to be twofold: they provide a substrate (and possible nutrient source) for epiphytic algae, and they facilitate the flow of phosphorus from sediments to the water column.

Possible Role of White Amur in Lake Conway

The Lake Conway model does not yet produce a reliable baseline simulation. However, variations within a 4-year period are reasonable; comparison of the effects of simulated introduction of white amur with these baseline simulations will indicate trends that should be watched for in Lake Conway.

Simulated effects of white amur grazing on macrophyte biomass are evident within 1 year after stocking; biomass declines to half the expected level after 3 years (Figure 3). Similarly, phytoplankton levels decline relative to the simulated baseline conditions (Figure 4). This would be caused by a net decrease in available phosphorus in the water column as macrophyte biomass decreases (Figure 5). Epipelic algae, on the other hand, show little change in biomass until the beginning of

Table 1

Primary Production in Lake Conway*

Producer	Biomass gC/m^2	Gross Primary Productivity gC/m^2-day
Phytoplankton	0.13	1.2
Macrophytes	36.9**	1.7
Benthic algae	1.0	0.3
Total		3.4

* Ewel, K. C., and T. D. Fontaine III. 1979. A model for evaluation of the response of the Lake Conway, Florida, ecosystem to introduction of the white amur. Technical Report A-78-2. U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

** Assumes epiphytic algae represent 30 percent of total weight.

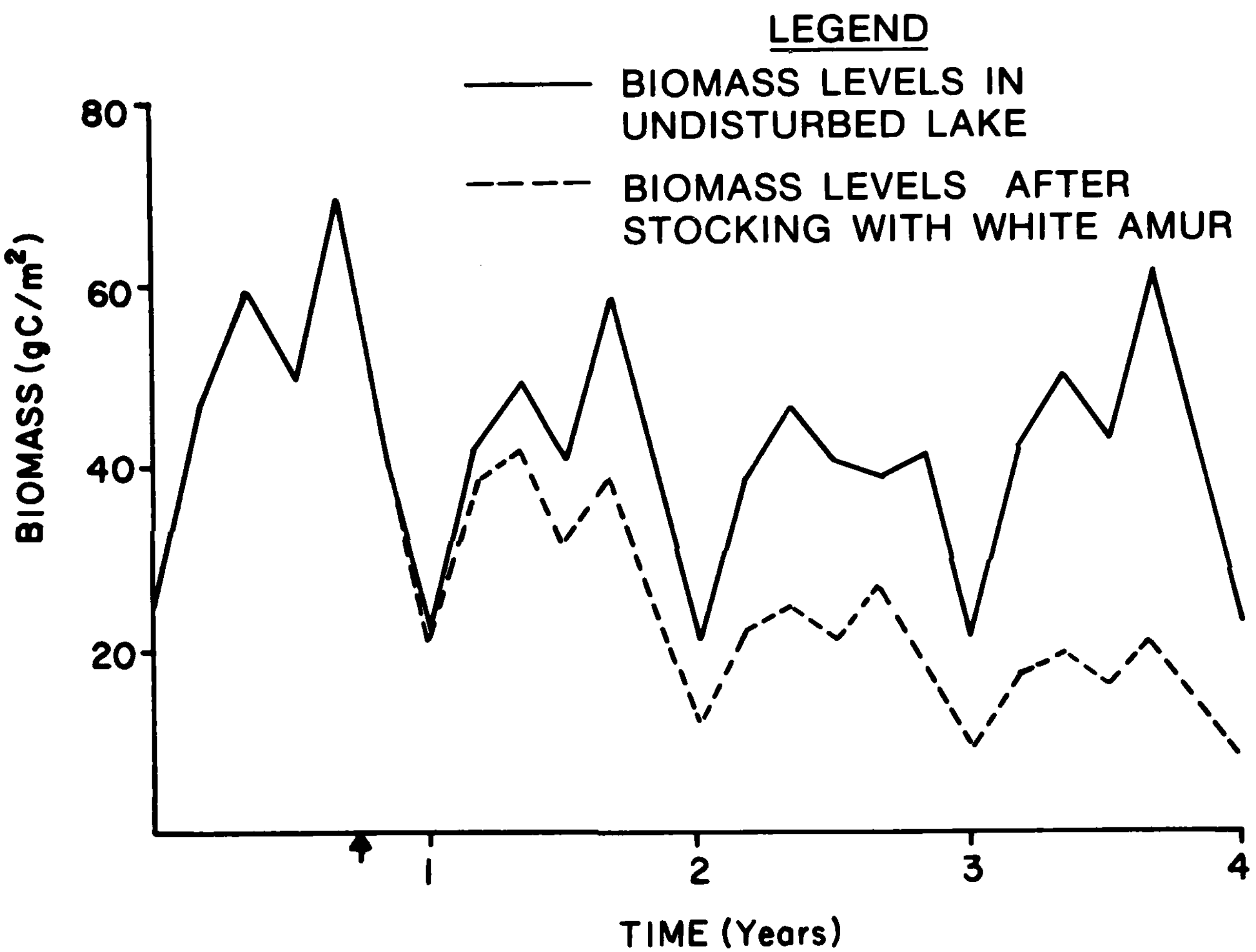

Figure 3. Simulated effect of white amur on macrophyte biomass. (Arrow denotes time of stocking)

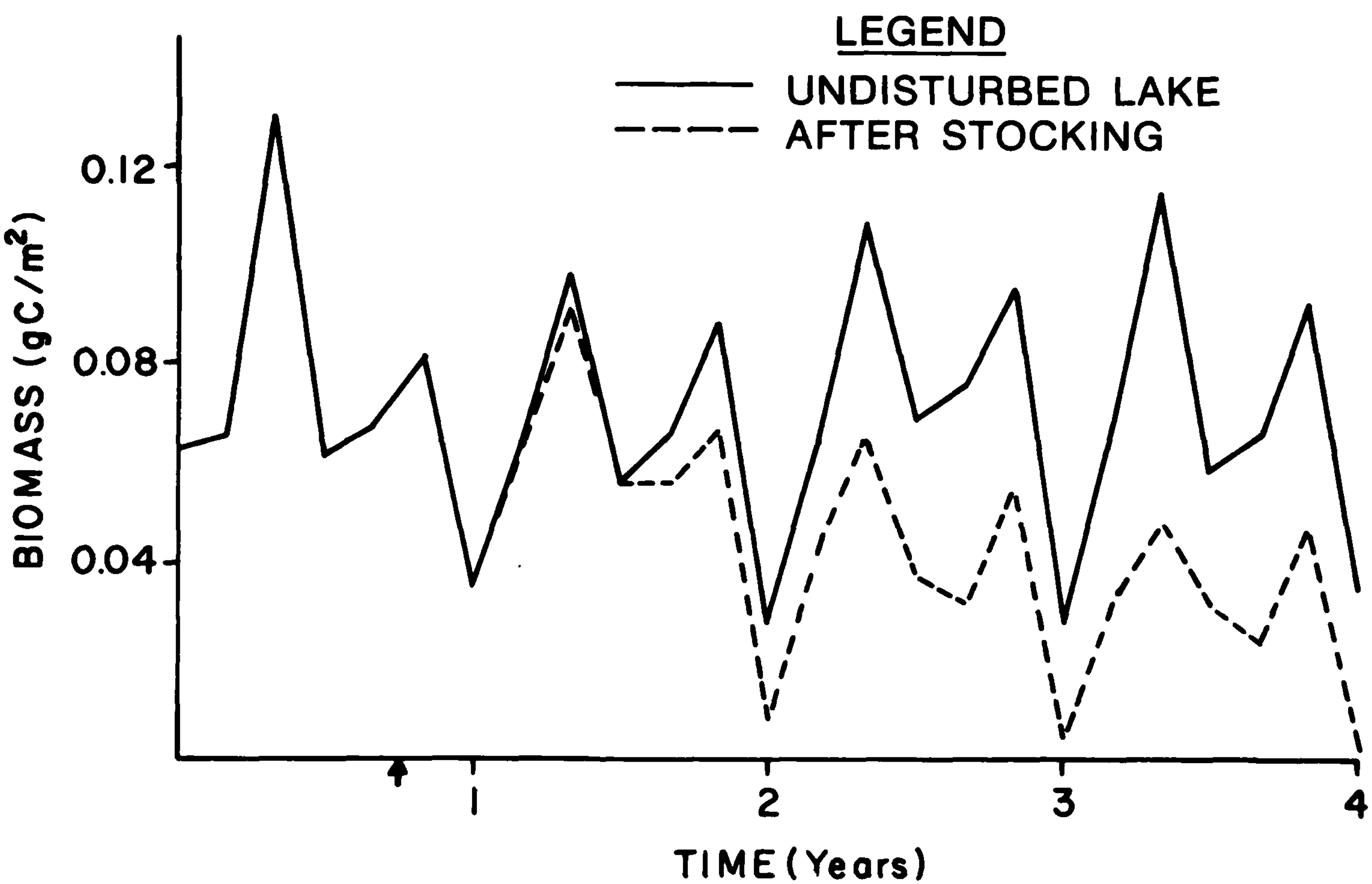

Figure 4. Simulated effect of white amur on phytoplankton biomass. (Arrow denotes time of stocking)

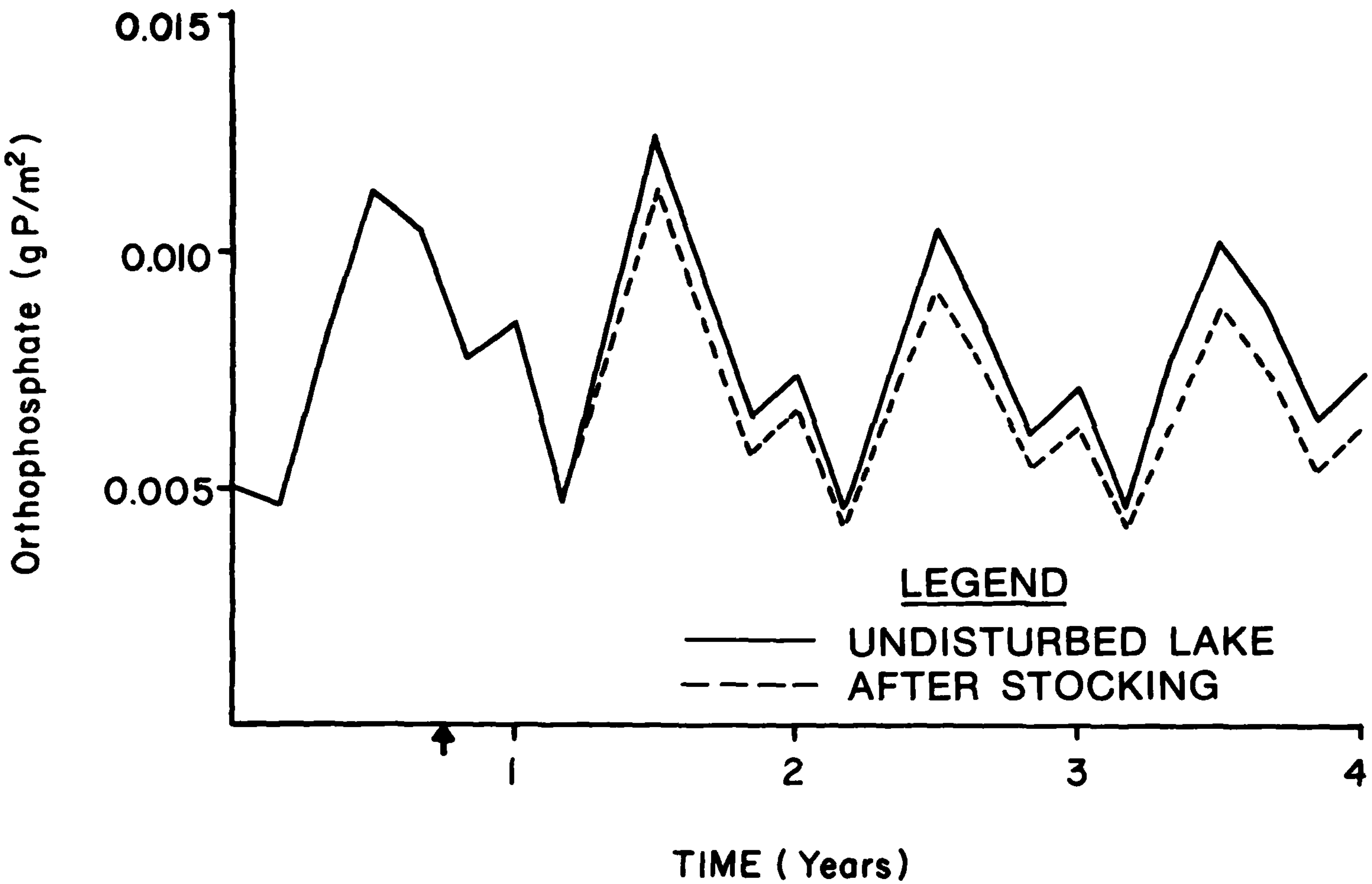

Figure 5. Simulated effect of white amur on orthophosphate levels. (Arrow denotes time of stocking)

the fourth poststocking year (Figure 6). Increase at this time reflects higher light availability since the shading caused by phytoplankton and macrophytes lessens.

Simulated zooplankton and herbivorous fish biomass levels decrease unrealistically and cause decreases in predatory fish populations that feed heavily on them. Consequently, the magnitude and direction of these changes are not reported. However, it is clear that the food chain within Lake Conway must shift from a grazing emphasis to a detrital base. Accordingly, simulated levels of benthic invertebrates, which depend primarily on epipelic algae and detritus, increase slightly over the three poststocking years that were simulated (Figure 7). A shift in species composition toward fish that can subsist on benthic organisms and dead organic matter would be expected.

Observed Changes in Lake Conway Productivity

Gross community production and respiration rates appear to have changed significantly from baseline estimates, although sampling frequency was insufficient to detect changes in seasonal patterns (Figure 8). Annual gross community production appears to have decreased, and annual community respiration has remained the same, leading to a slight decrease in net community production (Figure 9). Similar trends are evident in plankton productivity and respiration (Figures 10 and 11).

Metabolism measurements in Lake Conway therefore support the model's prediction that producer biomass levels (and biomass consumed by herbivores) will decrease after white amur are introduced, although more intensive sampling would be necessary to detect a significant change in metabolism rates.

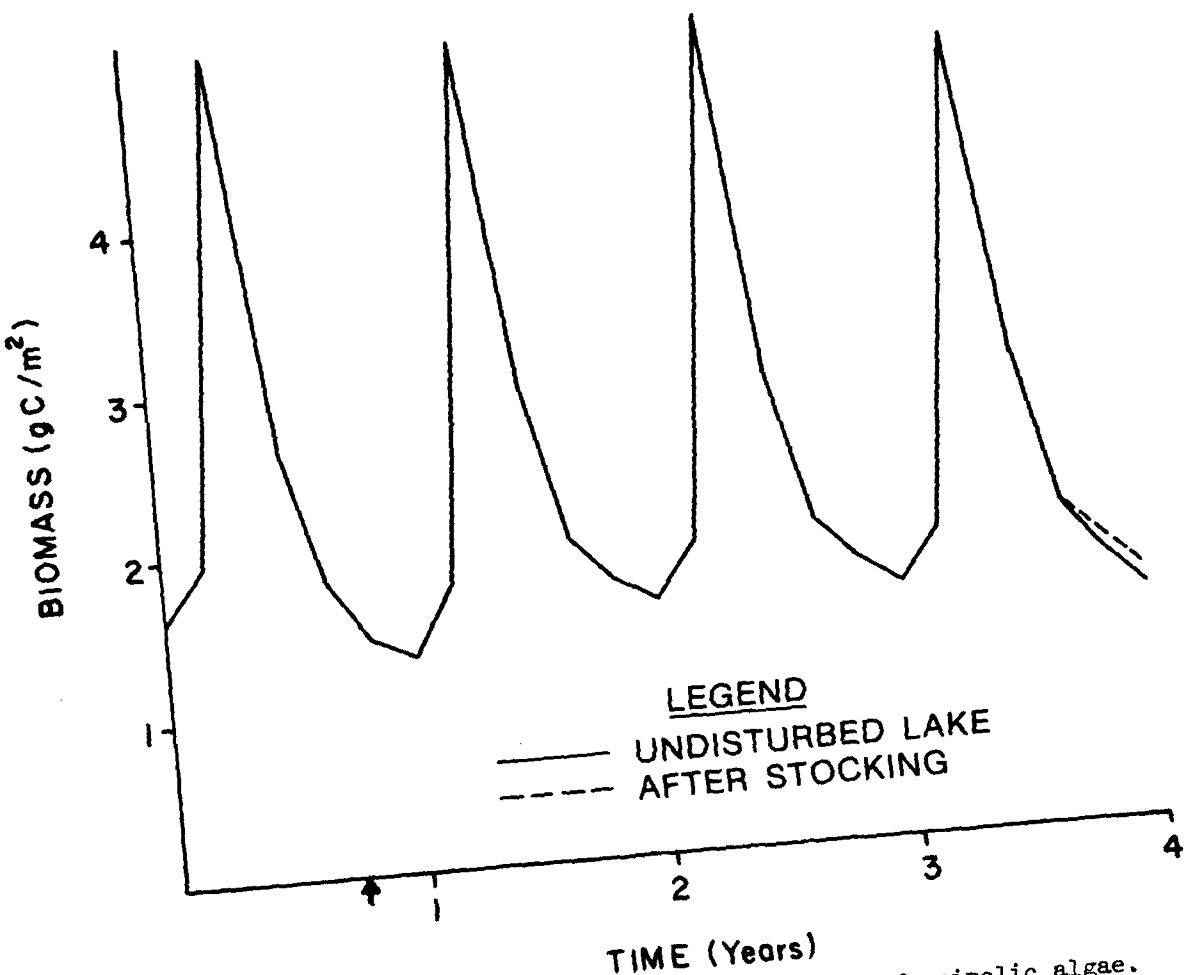

Figure 6. Simulated effect of white amur on biomass of epipelic algae. (Arrow denotes time of stocking)

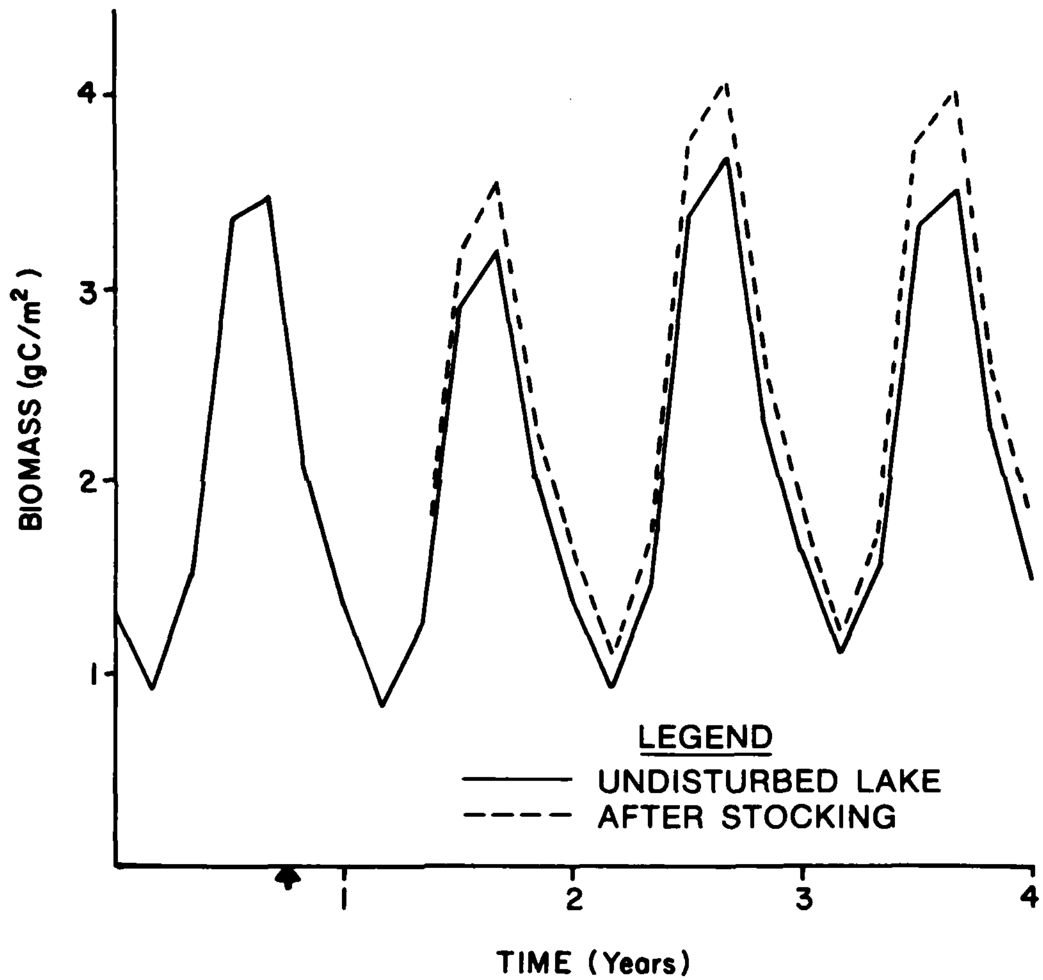

Figure 7. Simulated effect of white amur on benthic invertebrate biomass. (Arrow denotes time of stocking)

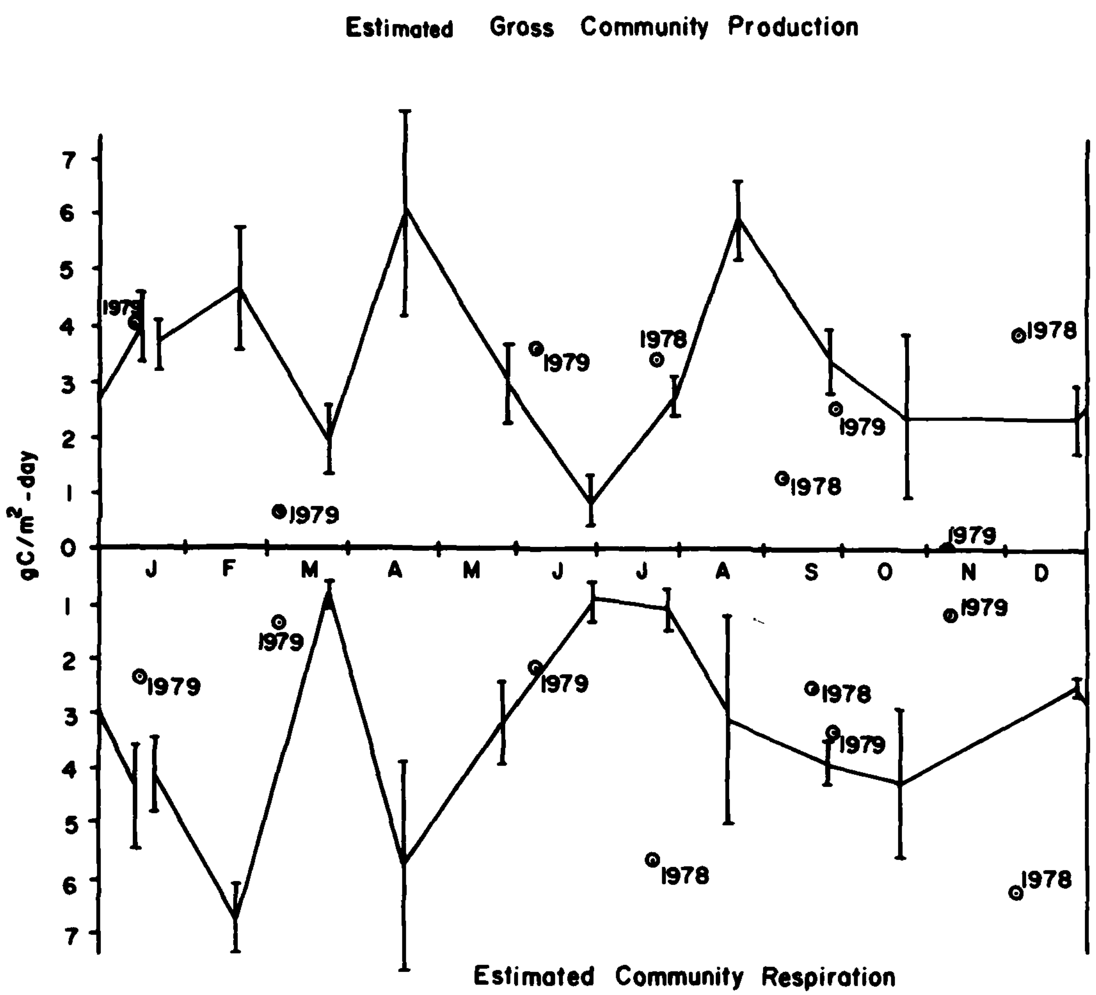

Figure 8. Gross community production and respiration rates in Lake Conway. Solid line indicates seasonal pattern in undisturbed lake (see Table 1). Circles represent measurements made in 1978 and 1979, after white amur were stocked

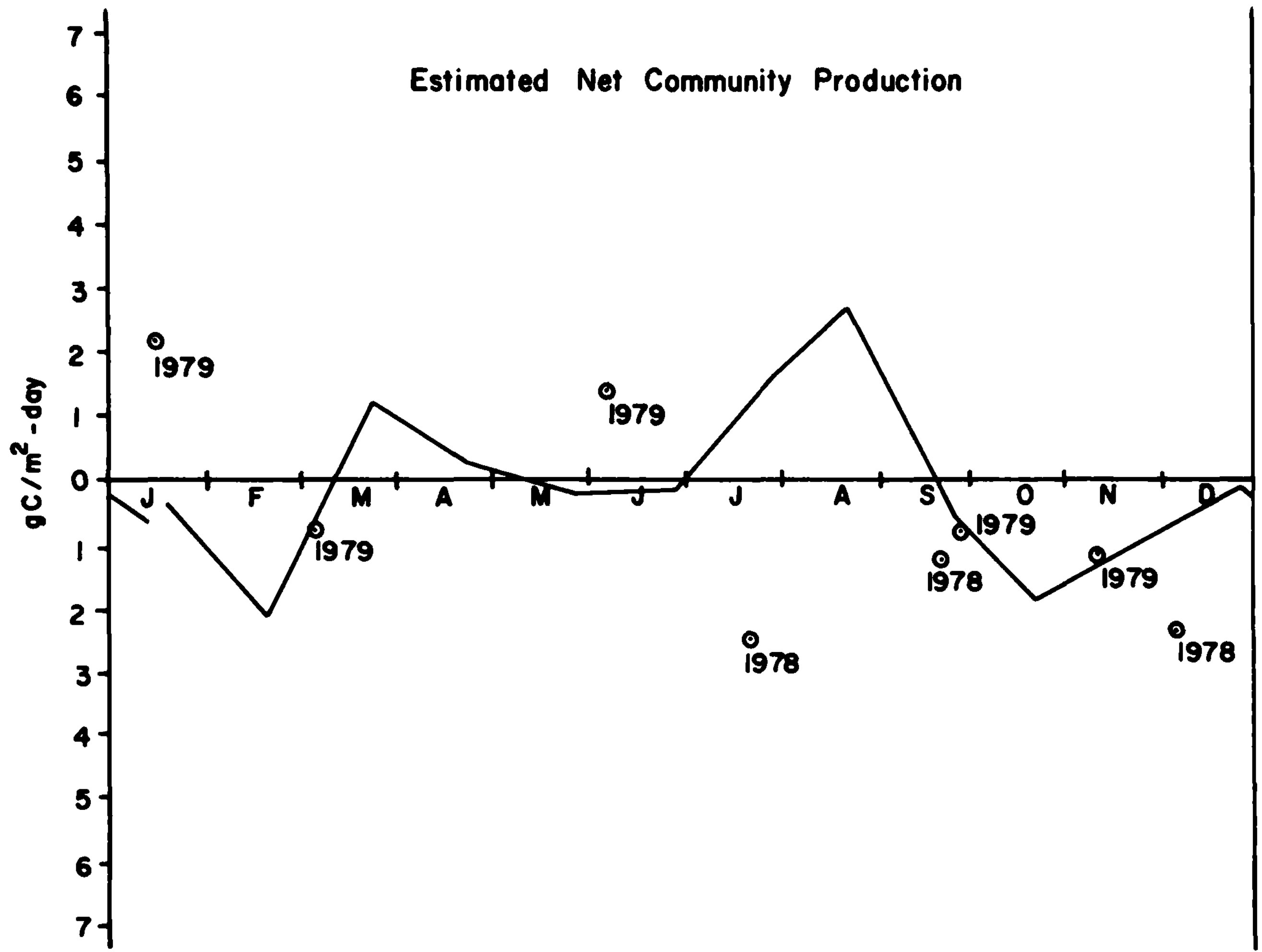

Figure 9. Net community production rates in Lake Conway. Solid line indicates seasonal pattern in undisturbed lake. Circles represent measurements made in 1978 and 1979, after white amur were stocked

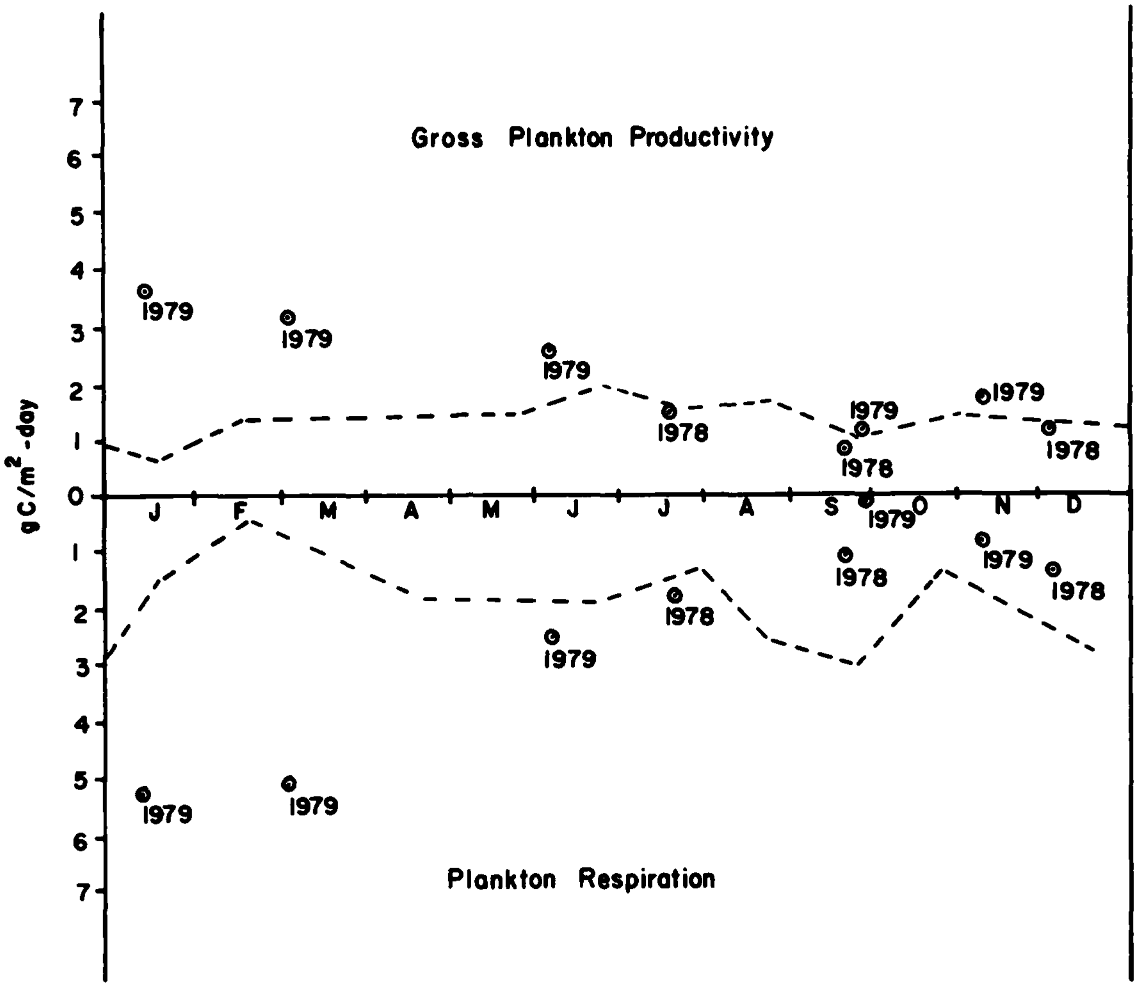

Figure 10. Gross primary production and respiration rates of plankton in Lake Conway. Solid line indicates seasonal pattern in undisturbed lake (see Table 1). Circles represent measurements made in 1978 and 1979, after white amur were stocked

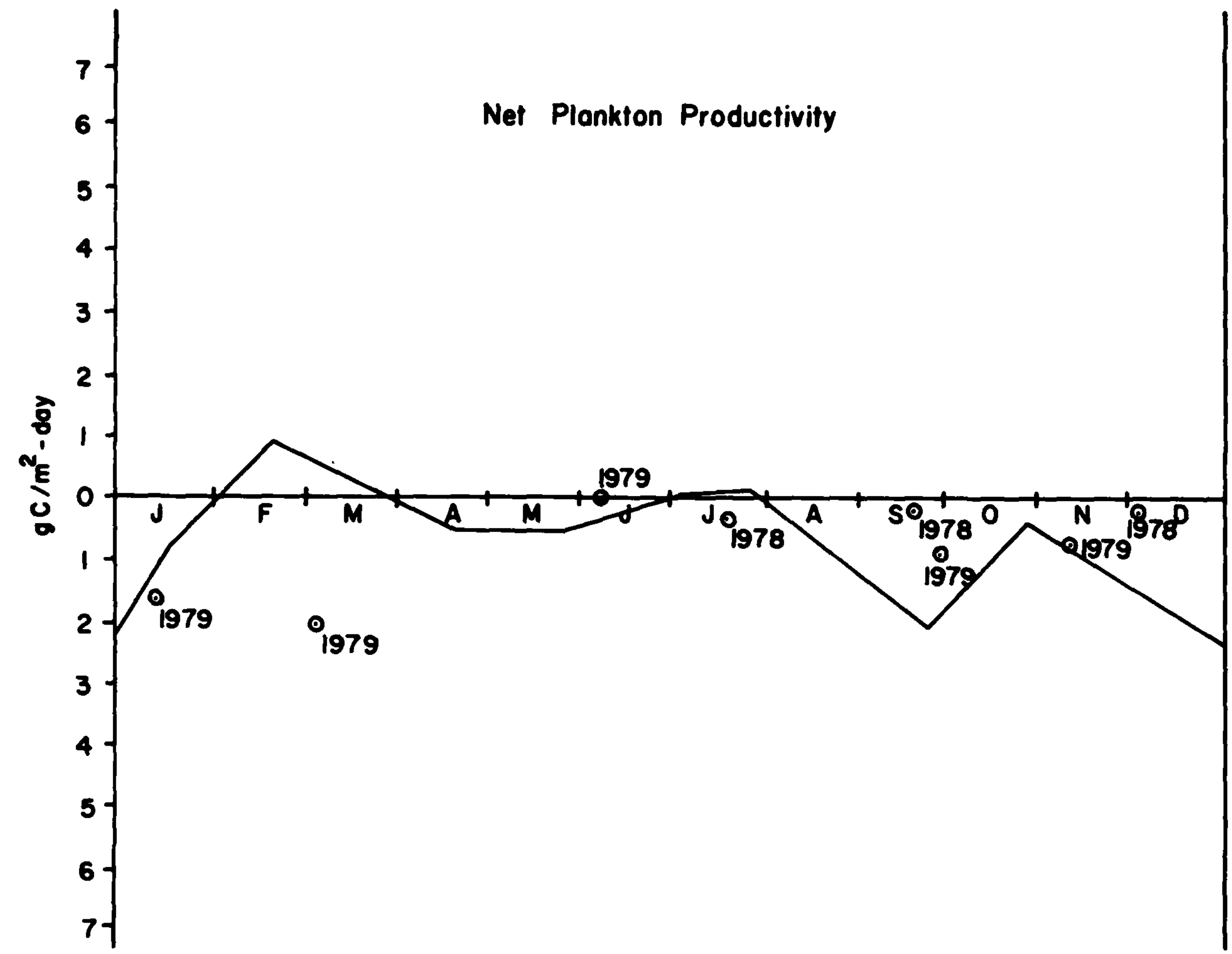

Figure 11. Net primary production rates of phytoplankton in Lake Conway. Solid line indicates seasonal pattern in undisturbed lake. Circles represent measurements made in 1978 and 1979, after white amur were stocked

LARGE-SCALE OPERATIONS MANAGEMENT TEST USING THE WHITE AMUR AT LAKE CONWAY, FLORIDA

Radiotelemetry Tracking of White Amur

by

Malcolm P. Keown*

As part of the ongoing data collection effort at Lake Conway, aquatic macrophytes are being monitored on a regular basis to detect any changes that may occur in species composition, biomass, spatial distribution, and general condition. Since the stocking of Lake Conway with white amur in September 1977, regular observations have indicated a definite effect on plant populations resulting from the fish's presence. The overall net effect will be determined after the data collection and analysis are completed. What cannot be determined from these observations is a correlation between fish movement within the lake system and the decline or occurrence of the macrophytes as a function of time. In order to establish this correlation, additional data are required. The examination of this problem has indicated that tracking fish movements at comparable time intervals to the other data collection efforts would provide the needed information.

Fish tracking using ultrasonic techniques dates back to 1951; radiotelemetry techniques were utilized beginning in 1968 as an outgrowth of terrestrial tracking. Most of the ultrasonic tracking has been done in the 30- to 150-kHz range. The optimum frequencies are 70 to 80 kHz due to minimum interference from underwater noise sources, i.e. outboard motors, flow past hydraulic structures, wave action, etc. The major detriments to ultrasonic propagation are turbulence and temperature gradients. Turbulence raises the ultrasonic background noise level. Temperature gradients often found along an ultrasonic propagation path render this mode unsuitable for direction finding techniques.

Radiotracking experiments to locate fish have been conducted on frequencies from 27 to 164 MHz. The two dominant factors affecting the propagation of radio signals through water in this part of the electromagnetic spectrum are the electrical conductivity of the propagation medium (water) and the radiation efficiency of the underwater antenna. The value of electrical conductivity is dependent on the quantity of electrolyte present and the transmission frequency; an increase in either parameter raises the conductivity. The effect of an increase in conductivity is to shorten the propagation path length over which communications can be maintained for a given transmitter/antenna and

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antenna/receiver configuration. Conversely, as the frequency is raised, the dimensions of the antenna in a fish radiotag become larger with respect to the transmission wavelength, thus increasing the radiation resistance of the antenna and in turn promoting a more efficient transfer of energy from the tag to the propagation medium. Because of these opposing factors, a trade-off must be made to establish an optimum operating frequency. Experiments have shown that the use of frequencies in the 30- to 50-MHz band present a good compromise between the high conductivities experienced at short wavelengths and the improvement in antenna radiation efficiency that results when a shorter wavelength is used.

Fish tracking technology has moved rapidly forward over the past few years. In 1970, radiotag design life was a matter of a few days; 4 years ago, commercially available tags could be purchased with design lives measured in terms of weeks; now tags have advertised lives in excess of 4 years. Currently used tag transmitters operate in a pulse mode, i.e., the oscillator is controlled by a triggering circuit that allows operation only during a very short part of the duty cycle, thus considerably lengthening the life of the tag. Although the power input of the tag transmitters now being used at Lake Conway is approximately one tenth of a milliwatt, the effective radiated power of the tag is much less because of the poor radiation efficiency of the antenna, as well as additional losses that occur because the transmitter is not 100 percent efficient in converting the power dissipated by the tag battery into electromagnetic energy.

Bench testing has shown that the radiation pattern of the Lake Conway tags is nearly spherical because the antenna is small as compared with the transmission wavelength. Thus, these fish tags can be considered for all practical purposes as a radiation point source. As an electromagnetic wave travels away from the tag towards an abovewater receiving antenna signal, attenuation is experienced over three distinct parts of the propagation path: through the water, at the air/water interface, and through the air. The signal attenuation through water is approximately 3.5 db/m at 49 MHz for an electrical conductivity of 200 μmhos/cm (Lake Conway water). As the wavefront approaches the air/water interface, only the portion of the incident signal that makes an included angle of 6.4 deg or less with the water surface normal is propagated across the interface (Figure 1). The remainder of the signal is reflected back into the water; thus, less than 0.5 percent of the power radiated from the tag is available to be transmitted across the air/water interface, exclusive of the losses incurred due to water attenuation between the tag and surface. Once the signal has crossed the interface, the remaining energy is distributed into vertically and horizontally polarized components.

Prior to a full-scale tracking effort at Lake Conway, a feasibility study was conducted at WES during the summer of 1978 to evaluate the effectiveness of radiotelemetry techniques for fish tracking. This study had three objectives:

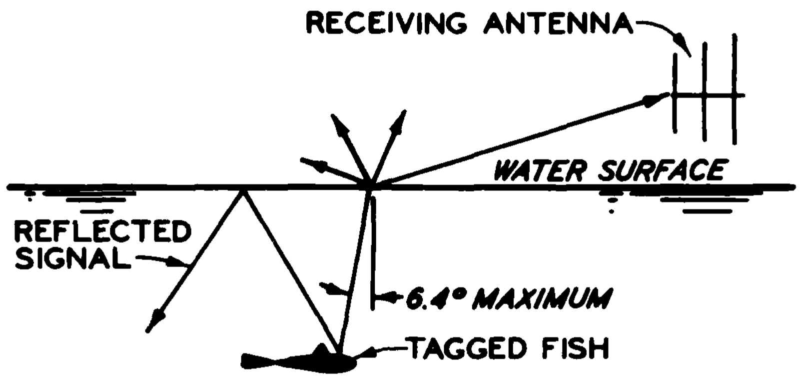

Figure 1. Signal propagation path from tagged fish to receiving antenna

a. To determine a typical maximum working range and depth for commercially available fish tracking equipment.

b. To determine the best type of receiving antenna for locating a tagged fish.

c. To tag two fish and track them over a 4-week period.

The reservoir at Lake Park, south of Vicksburg, was found to have an electrical conductivity of 180 μmhos/cm, which is very close to the conductivity value of the water in the Lake Conway system. A test range was laid out at Lake Park to determine the maximum signal detection depth for selected horizontal ranges. The results of this test series indicated that signals could be detected from a conventional fish tag at a 2-m depth over a horizontal distance of 900 m. At distances less than 200 m, detection depths in excess of 6 m were realized. Several receiving antennas were tested with a vertically polarized three-element yagi proving to have the best gain and azimuthal accuracy. Two fish were tagged at Lake Park in August 1978, and their positions were successfully located over a 6-week period.

Having determined that fish could be successfully tracked using radiotelemetry techniques, a mobile tracking unit was assembled at Lake Conway (Figures 2 and 3). Note that two yagis are used here for improved azimuthal resolution. The antenna system is called a null-peak array. When the yagi transmission lines are the same length, the signals are additive resulting in a 3-db gain over a single yagi. When a half-wave section is added to one of the transmission lines, the signals are 180 deg out of phase with each other, resulting in a deep null in the array radiation pattern. The null azimuth, which is determined by a minimum reading of the receiver's signal strength meter, occurs at the same azimuth as the azimuth towards the tagged fish. Typical azimuthal error with the yagis in phase is 10 and 3 deg when they are 180 deg out of phase.

Since May 1979, 20 fish have been tagged at Lake Conway (Figure 4). Nine individuals are currently being located on a daily basis; of the

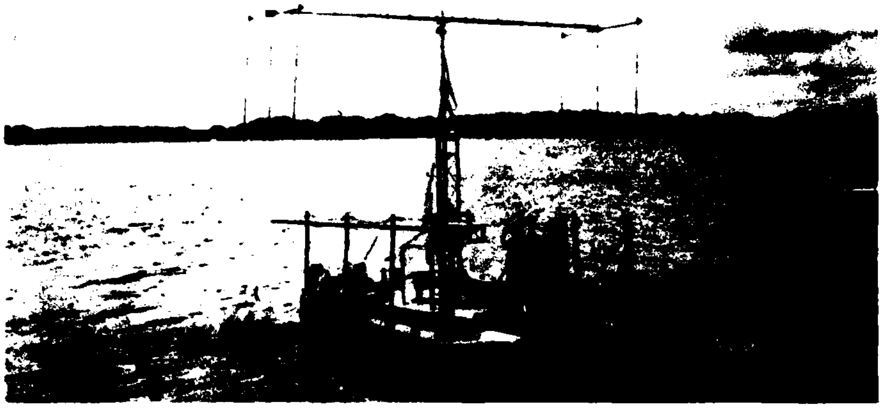

Figure 2. Mobile tracking unit at Lake Conway

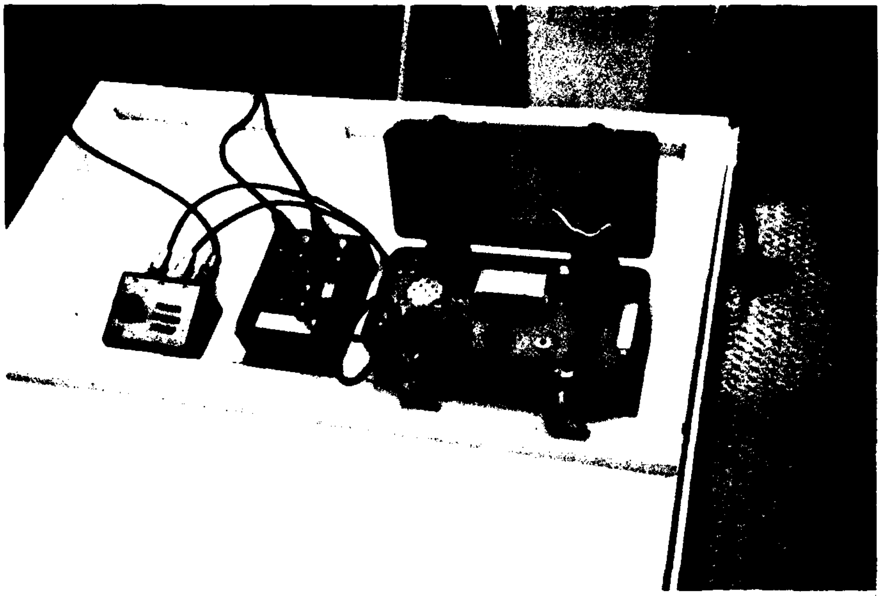

Figure 3. Receiving equipment used at Lake Conway. A coaxial antenna switch is shown on the left, the 180-deg transmission line phase shift unit in the center, and the radiotelemetry receiver on the right

Figure 4. Radiotag being inserted into white amur

remainder, three fish are assumed to be dead, three have moved into areas that are currently not actively being sampled, and five have disappeared, presumably as a result of transmitter failure or removal from the lake system.

Two methods have been used to locate the fish. The first method used was simple triangulation. Initially, the location of the mobile tracking unit was determined by triangulating with at least three known points on the shoreline. An observation site and compass rose attached to the mast of the antenna array were used to determine the relative angles between these known points. This location was then plotted on a map of the pool using a swing-arm protractor. The azimuth to a radio-tagged fish was initially determined by rotating the antenna in the general direction of maximum signal amplitude with the yagis in phase; the measured azimuth was then determined by switching in the 180-deg phasing line and rotating the antenna until the null in the radiation pattern was obtained. The orientation of the antenna array was then the same as the azimuth from the tracking unit to the fish. This azimuth was laid out on the pool map from the previously plotted location of the tracking unit. After completing this procedure from at least three locations, the position of the fish was estimated to be at the intersection of the azimuths.

The triangulation method of acquiring data has proven to be somewhat slow. A quicker and probably more accurate method has been developed as a result of field experience. Using the second approach, the antenna array is oriented broadside with the direction of travel of the mobile tracking unit. The driver of the craft then proceeds in the

direction of maximum signal amplitude. As the tracking unit passes over the location of the fish, there is a drastic reduction in signal strength; this is explained by the fact that the front-to-back ratio of the antenna array is in excess of 20 db. After passing over the fish, the craft then circles back to the estimated position of the fish to verify the location. If this location is close enough to shore so that the position of the tracking unit is known, the location of the fish can be plotted directly on a pool map; if the location is far from land, it can be determined by triangulating with known points along the shoreline.

The procedures that have been described herein can only be used to determine the surface location of a tagged fish. As part of this study, an attempt is being made to develop a technique to estimate tag depth as a function of signal strength. Four variables determine the signal strength of an implanted fish tag at a given receiving location: the electrical conductivity of the water, horizontal range, depth, and the antenna radiation pattern of the tag. The electrical conductivity of Lake Conway is constant throughout the system and thus would not affect the relative signal strength. As indicated, range can be estimated with good accuracy by the methods described previously and, therefore, is a known parameter. The radiation pattern of the tags is essentially a point source; it follows then that a tag's orientation is of no consequence. Thus, the tag depth can be possibly estimated from signal strength alone. Studies are now being conducted to determine if this approach is feasible. The end product is anticipated to be a nomograph that will provide an estimate of depth as a function of signal strength.

LARGE-SCALE OPERATIONS MANAGEMENT TEST USING THE WHITE AMUR AT LAKE CONWAY, FLORIDA

Procedure for Radiotagging of White Amur for Tracking Studies

by

Larry E. Nall* and Jeffrey D. Schardt*

Introduction

Intensive studies of the effect of the white amur on vegetation are under way[1] and definite declines in vegetation have been noted. However, WES scientists have decided that a correlation between vegetative decline and fish presence would be desirable and thus initiated a study[2] to determine the feasibility of using telemetry techniques in Lake Conway. The study reviewed and tested various types of equipment and concluded that a fish tracking study should be included in the Lake Conway project.

It was decided that the Florida Department of Natural Resources (DNR) would be able to incorporate the telemetry research into their present workload. Also, after studying the vegetation for nearly 3 years, DNR was in a better position to interpret the tracking data in relation to plant communities and had ready access to amur for implanting transmitters and had considerable experience in handling the fish.

Questions we hope to answer by this research are:

a. Do the fish remain stationary or move during feeding?

b. Is there any preference for food type?

c. What is the relationship between water temperature and feeding activity?

d. Is there any preference for specific areas?

e. Does activity vary according to time of day?

f. Is there any preference for depth zone?

g. Is there any interchange among pools?

h. How much variability is there in individual behavior?

i. Is there any gregarity among individuals?

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* Florida Department of Natural Resources, Orlando, Florida.

Methodology

Radio equipment

The WES staff has constructed a small pontoon boat to carry the rotating yagi antenna (Figure 1). An AVM Instrument Co. Model LA12 48 channel receiver is being used (Figure 2). Thirty AVM SM1 fish module transmitters were available to be installed in white amur. The transmitters are approximately 11 cm in length, 3 cm in diameter, and weigh an average of 61 g (less than 1 percent of the total weight of the fish in which they were installed). Battery life is claimed to be about 4 years. The system operates between 49.605 and 50.075 MHz.

Location techniques

Two methods are used for locating the fish. Each fish can be found by triangulation using two (preferably three) readings (Figure 3). To do this it is necessary to firmly anchor the boat and locate its position by measuring the azimuths of three landmarks of known position. A heading of 0 deg is assigned to one of these landmarks and the position of the transmitting fish is measured relative to this heading by noting the direction of maximum signal strength. Another location method is simply to pursue the fish with the tracking boat until the maximum signal strength is found and then determine that position in the above manner. The second method has been used exclusively since mid-July. Both methods of tracking were compared using submerged, unimplanted transmitters at depths ranging from 1 to 6 m. The second method proved not only to be twice as fast as triangulation, but also extremely accurate. Each transmitter was found within 5 m of the boat. The triangulation method usually located the fish within a 300- to 700-sq-m area. Once located, points are plotted on a map of the pool. These points can also be recorded in a tabular form by using a six-digit coordinate system developed specifically for the Lake Conway project. An example of this system is given in Figure 3. In addition to location, time, signal strength, weather, boating activity, and radio interference are noted at each sighting.

Implantation

The fish used for the implanting procedure were obtained from other ponds and lakes using rotenone (a fish toxicant) removal techniques, which are most effective on the white amur.[3] Only female fish weighing between 13 and 18 lb were used, thus duplicating the fish sex and size already in Lake Conway. To retain these fish before and after the implanting procedure, a temporary holding facility (Figure 4) was constructed on the shore of Lake Conway in front of the DNR field office. The facility used 1200-ℓ holding tanks and a lake water flow-through system.

A V-shaped surgical trough was constructed to hold the fish ventral side upward with the gills submersed in an aerated 80-ℓ aquarium (Figure 5). The fish were initially anesthetized in a 4 ppm quinaldine

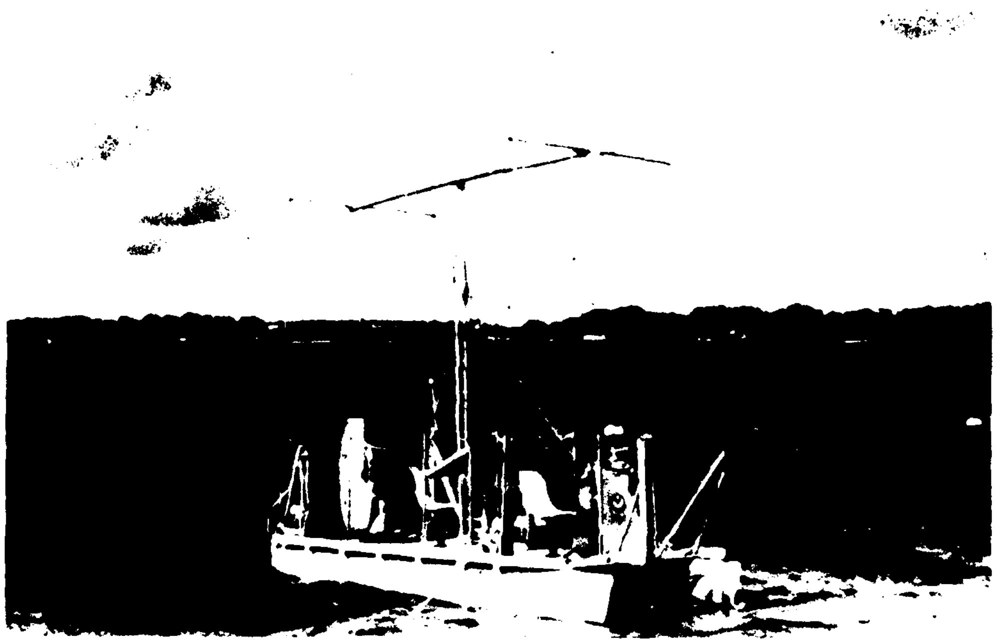

Figure 1. Telemetry boat with yagi antenna

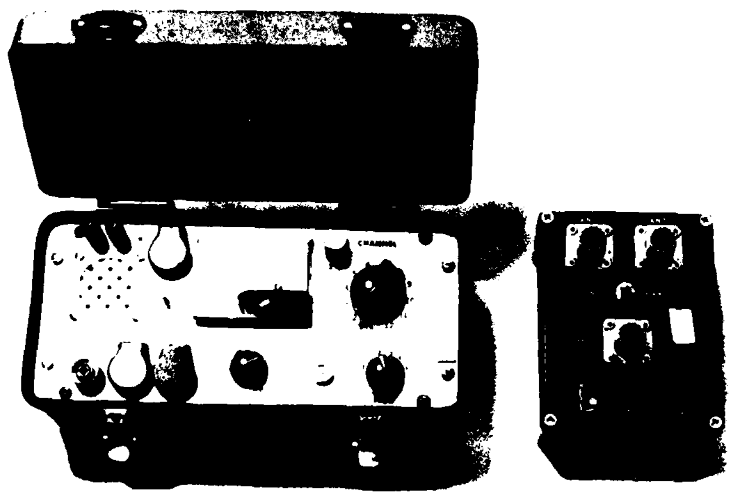

Figure 2. AVM 48 channel radio receiver

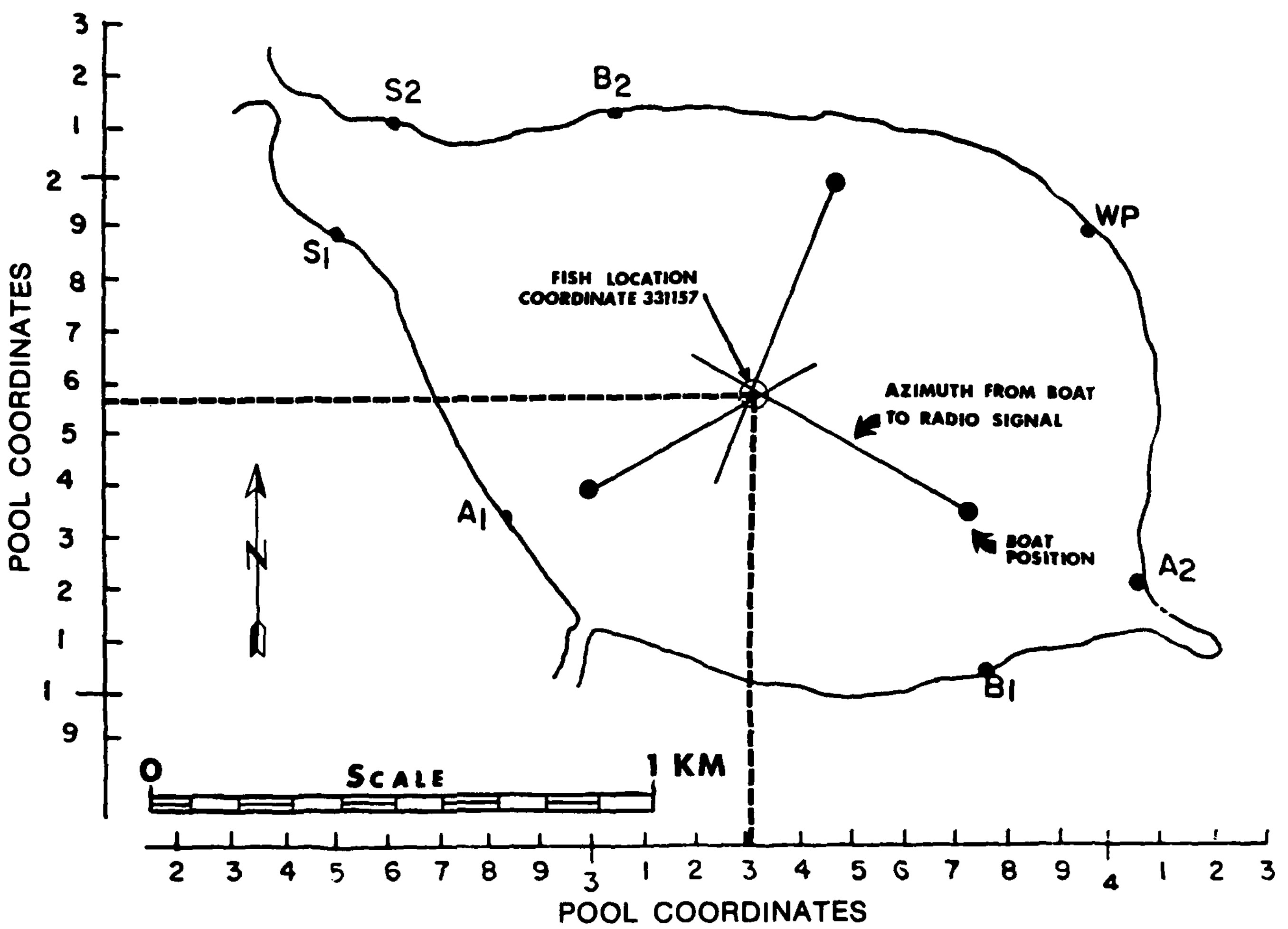

Figure 3. Example of triangulation technique and coordinate system

Figure 4. White amur holding facility

Figure 5. Surgical holding trough

solution in one of the holding tanks. This aided handling during weighing and transferring to the operating tank. A quinaldine solution of 4 to 15 ppm was used in the surgical tank depending on the amount necessary to prevent movement for each individual.

Once suitably anesthetized, two to three rows of scales were removed around the incision site. A 5- to 7-cm incision was made vertically just anterior to the pelvic fin girdle (Figure 6). The lower end of the incision stopped about 2 to 3 cm from the midventral line. This incision site was chosen because the transmitter and viscera place a strain on the sutures on a longitudinal midventral incision, which could cause the wound to reopen.[4] The transmitter was inserted into the abdominal cavity and positioned at the lowest point. All instruments and the transmitter were soaked in alcohol before use, and sterile gloves were worn, but no further attempt at sterility was made. All fish were confirmed to be female by the presence of eggs.

Figure 6. Incision site

Closure was accomplished using 000 Type C Chromic Gut suture material. Four to six deep stitches were made through the body wall using a 6 D half circle cutting suture needle. Five to seven shallower stitches were made through the epidermis using a smaller 8 D half circle cutting needle, which ensured a tight closure (Figure 7).

After closure, 10 ml of injectable terramycin solution, which contains 50 mg/ml oxytetracycline hydrochloride, was administered

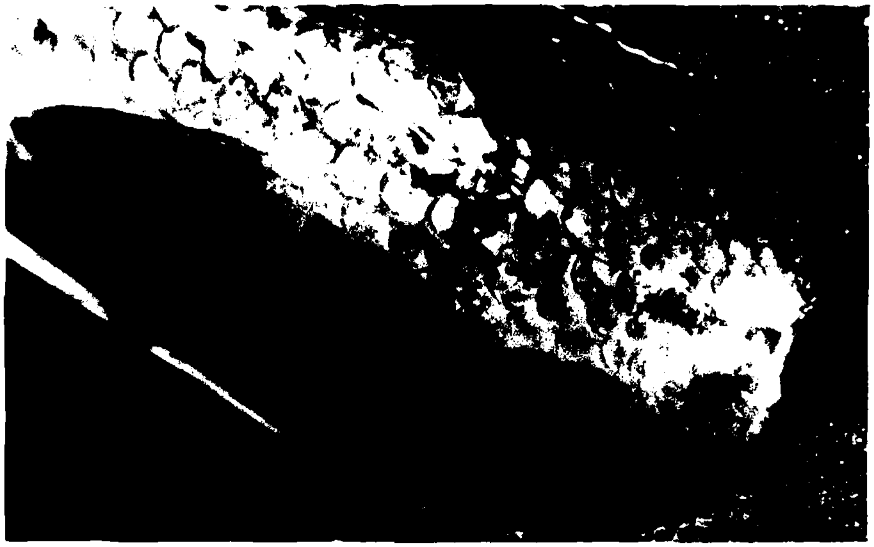

Figure 7. Closed incision

intramuscularly. This was a dosage of approximately 55 mg oxytetracycline per kilogram of body weight. Intraperitoneal injections and antibiotic ointment applied directly to the incision were considered but rejected because of a suggestion that this might dissolve the suture material prematurely.

After implantation the fish were returned to holding tanks for a 24-hr observation period before release. In some of the later operations a few of the fish were released immediately after recovery because of crowded conditions in the holding tanks.

Each pool was stocked with implanted fish in proportion to the total number of fish originally stocked in Lake Conway. However, the Middle Pool was not stocked because of its large size, lack of diverse habitat, and greater depths, although three fish were released in the Middle Pool before this decision was made. It is felt that the amount of knowledge gained from this pool versus the amount of effort to find the fish would not be acceptable. The number of fish released is as follows:

Pool	Radio Fish Released
South	12
Middle	3
East	7
West	8
	30

Analysis

Results can be easily interpreted by comparing fish location maps with depth and plant distribution maps. The literature review should indicate what types of statistical analyses are utilized for this type of data; however, use of statistical methods in this type of study may be superfluous. Computer methods of mapping fish coordinates and comparing them with the vegetation and depth maps are being investigated. However, implementation of such a system may be more time-consuming than manual mapping techniques.

Status and Preliminary Results

Radio equipment

The radio equipment used in the project was reliable. None of the thirty transmitters failed or weakened until 22 October 1979. Since that date four implanted transmitters have failed; two control transmitters, which have not been implanted, have quit transmitting; and the beat frequencies of two others have slowed so much that accurate tracking is nearly impossible. Excluding the three Middle Pool fish, this leaves eleven reliable transmitters in the lake and eight transmitters to be installed in early December. Characteristics of the transmitters are presented in Table 1. Note that the beat rate occasionally differs considerably from the rate claimed by AVM. A new, more sensitive receiver was purchased by WES but it did not function properly when tested by the WES technician. The receiver was returned to AVM for repair.

Implantation

Twelve female fish were captured from Lake Holden in Orlando on 24 April 1979. Ten of these fish were acceptable and implanted on 2, 3, and 4 May 1979. All of these fish survived the operation and were released after 24 hr. No mortality has been experienced with these ten fish. Thirty fish were obtained from Fort Lauderdale ponds on 7 and 8 August. These fish were transported to Orlando and implantation took place on 10 August. Because of exceptional stress caused by capture and transportation in midsummer temperatures, many of these fish died before surgery was attempted. Several of the fish were in such poor condition before the operation, they did not recover afterwards. Transmitters were removed from these fish. Ten fish in fair condition were released. There is an indication that two of these fish have died. Searches using SCUBA will be initiated to recover the transmitters using a special submersable loop antenna designed by the WES technicians. Characteristics of released fish are summarized in Table 2. The remaining eight operable transmitters will be implanted during December so that the cooler weather will not have the same harmful effect as in August.

Table 1

Transmitter Characteristics

Transmitter	Bank	Channel	Opt Freq	BPM (Specified)*	BPM (Actual)	Fish No.	Pool**
14251	1	1		83		1	S
14252	1	2		70		2	S
14253	1	3		92		3	S
14254	1	4		92		4	S
14255	1	5		86		5	S
14256	1	6		79		6	S
14257	1	7		71		7	S
14258	1	8		79		8	M
14259	1	9		80		9	M
14260	1	10		83		10	M
14261	1	11	4.25	80	80	11	S
14262	1	12	4.50	116	116		
14263	2	1	3.50	97	102	13	S
14264	2	2	4.00	88	90	14	E
14265	2	3	4.00	74	78		
14448	2	4	4.00	110	120		
14449	2	5	3.50	84	76	17	E
14450	2	6	3.50	101	100	18	E
14451	2	7	3.50	96	90	19	E
14452	2	8	3.75	120	116	20	E
14453	2	9	3.75	72	72		
14454	2	11	3.50	96	92		
14455	2	12	3.60	103	110	23	W
14456	3	1	3.25	96	94		
14457	3	2	3.50	100	92	25	W
14458	3	3	3.25	108	112	26	
14459	3	4	3.50	130	128		
14460	3	5	3.25	100	100		
14461	3	6	3.25	72	74		
14462	3	7	3.25	108	110		

* BPM = beats per minute.

** S = south, M = middle, E = east, W = west.

Table 2

Telemetry Fish Data

Fish No.	Transmitter No.	Total Length, cm	Weight, lb	Pool Stocked*	Date Stocked
1	14251	84.5	12.88	S	5/3/79
2	14252	81.5	15.31	S	5/3/79
3	14253	87.1	16.13	S	5/3/79
4	14254	81.0	15.06	S	5/4/79
5	14255	82.8	16.69	S	5/4/79
6	14256	83.0	16.75	S	5/4/79
7	14257	88.5	18.74	S	5/4/79
8	14258	83.5	14.41	M	5/5/79
9	14259	87.8	18.81	M	5/5/79
10	14260	84.0	13.69	M	5/5/79
11	14261	79.0	15.50	S	8/10/79
13	14263	73.0	15.50	S	8/10/79
14	14264	85.0	16.75	E	8/10/79
17	14449	82.0	17.00	E	8/10/79
18	14450	81.0	13.00	E	8/10/79
19	14451	78.0	13.00	E	8/10/79
20	14452	81.0	15.00	E	8/10/79
23	14455	82.0	16.25	W	8/11/79
25	14457	87.0	17.50	W	8/11/79
26	14458	77.0	13.50	W	8/11/79

* S = south, M = middle, E = east, W = west.

Other equipment

Of all the various phases of the study, by far the most trouble was caused by the tracking boat. Initially, the boat was equipped with a fan motor. The fan propulsion was most inefficient: top speed was 5 mph, it was loud, and maneuverability was poor. A transom assembly had to be constructed and welded on the boat so that an outboard motor could be used. Adding this structure, acquiring an acceptable motor, and installing the steering and control cables lost several weeks of tracking time.

The anchoring system also had to be modified. At first, the boat was anchored at each corner by a Danforth type anchor. This system was ineffective because the torque from antenna rotation caused the boat to rotate many degrees from its 0-deg azimuth, thus invalidating the directional reading. Also, the anchors were very difficult to pull up. Two metal collars were welded to the side of the boat and 6.10-m aluminum poles were inserted through the collars thus firmly anchoring the boat. This system worked well but had to be reinforced when the collars were torn from the light metal to which they were attached. Perfection of the anchoring system also cost several weeks tracking time.

Tracking

Since the predominance of observations have been taken in South Pool, which has been stocked with implanted fish much longer than the other pools, the following results and discussion will deal primarily with that pool.

Thirty-five days were devoted to tracking between 5 June and 12 November. This includes two diurnal sampling periods. Number of observations per fish are shown below:

Fish	Sightings	Fish	Sightings
1	31	6	18
2	27	7	18
3	35	11	16
4	37	13	16
5	38	Total	236

Positions for each fish have been plotted and connecting lines drawn to show distance traveled between sightings and bottom type crossed as the fish moved from point to point. These are presented in the Appendix. Dotted lines represent elapsed periods greater than 1 week between sightings. A map with all the sightings for all the fish to date is shown in Figure 8.

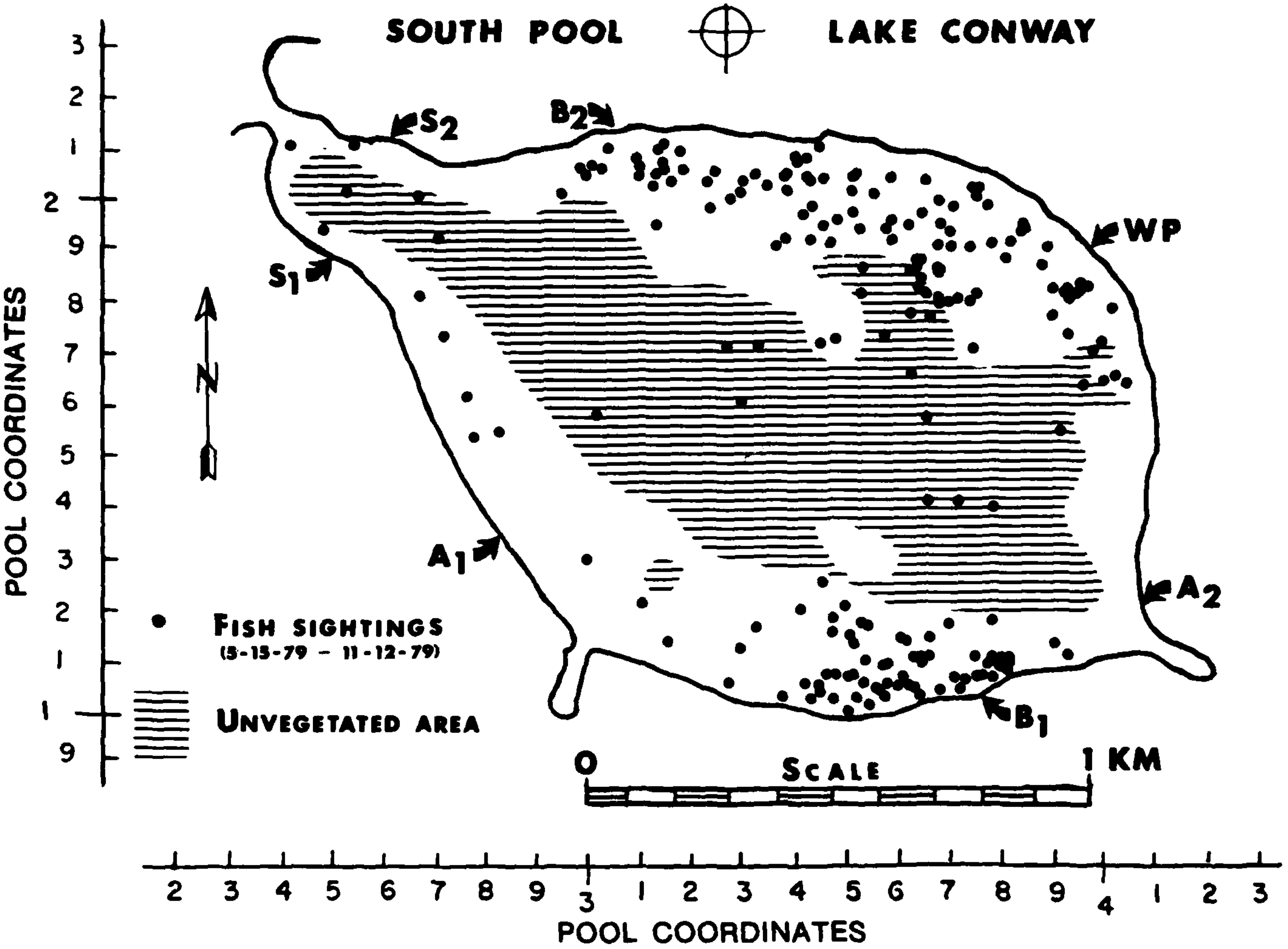

Figure 8. Cumulative sightings plotted on vegetation map, South Pool

Discussion

Examination of the composite map in Figure 8 shows a distinct preference by all of the fish for two areas along the north shore and south central shores of South Pool. Comparison of these locations with a vegetation map shows that the fish are concentrating in dense areas of *Nitella* and occasionally *Potamogeton*. Comparison with a depth map (Figure 9) shows that most of the sightings (221 of 236) vary from 1 to 3 m in depth. The Iowa Conservation Commission[5] also conducted telemetry studies with the white amur in conjunction with an impact project. Results showed that most of the fish preferred shallow water (less than 3 m). In Iowa, as in South Pool, fish were generally sedentary, particularly around weeded areas. Fish sighted in deeper water in the center of South Pool may either be transitory or feeding on *Hydrilla* which grew in deeper waters. It is believed that they were transitory since fish were never found in deep water on consecutive sightings. Also, vegetation studies under way in Lake Conway show that *Hydrilla* had nearly been eliminated in South Pool by June 1979. The introduction of the fish into the lake came too late into the project to show preference between *Hydrilla* and *Nitella* by feeding location.

Examination of the maps for individual fish (in the Appendix) shows variations in behavior among the fish. Fish No. 1 prefers the southern shore of the pool; however, it crossed the pool to explore the northern shore and returned to the south shore that night covering nearly 2 km in a 24-hr period. This occurred during a diel sampling. Number 2 has crossed several times between the south and east shores. No other shoreline locations have been recorded for fish No. 1 and No. 2. Fish No. 3 is a wanderer that generally prefers the north-central area. Although it has come close to leaving South Pool on three different occasions it has not yet done so. Fish No. 4 and No. 5 preferred the north shore until early November. Both are presently on the south shore of South Pool. Fish No. 6 and No. 7 showed no clear preference for any particular area. Fewer sightings are available for these two fish because of their wandering habits and the fact that they have not been found since mid-October in South or Middle Pool. When in deeper water, location is difficult or impossible, and it is possible that these transmitters have also failed. Fish No. 11 and No. 13 were only recently stocked and have moved little. They are apparently recovering slowly from surgery or have died.

The East and West Pools were stocked on 14 August 1979. The fish from West Pool moved directly to East Pool where they have remained (Figure 10). It is apparent, as in South Pool, that these fish prefer the vegetated shallow areas of the lake. Most sightings (56 of 64) are again less than 3 m (Figure 11).

Nine remaining transmitters will be implanted and the fish released in the East and West Pools in early December. With the lower workload in December and barring unforseen difficulties, tracking will proceed on a more regular basis.

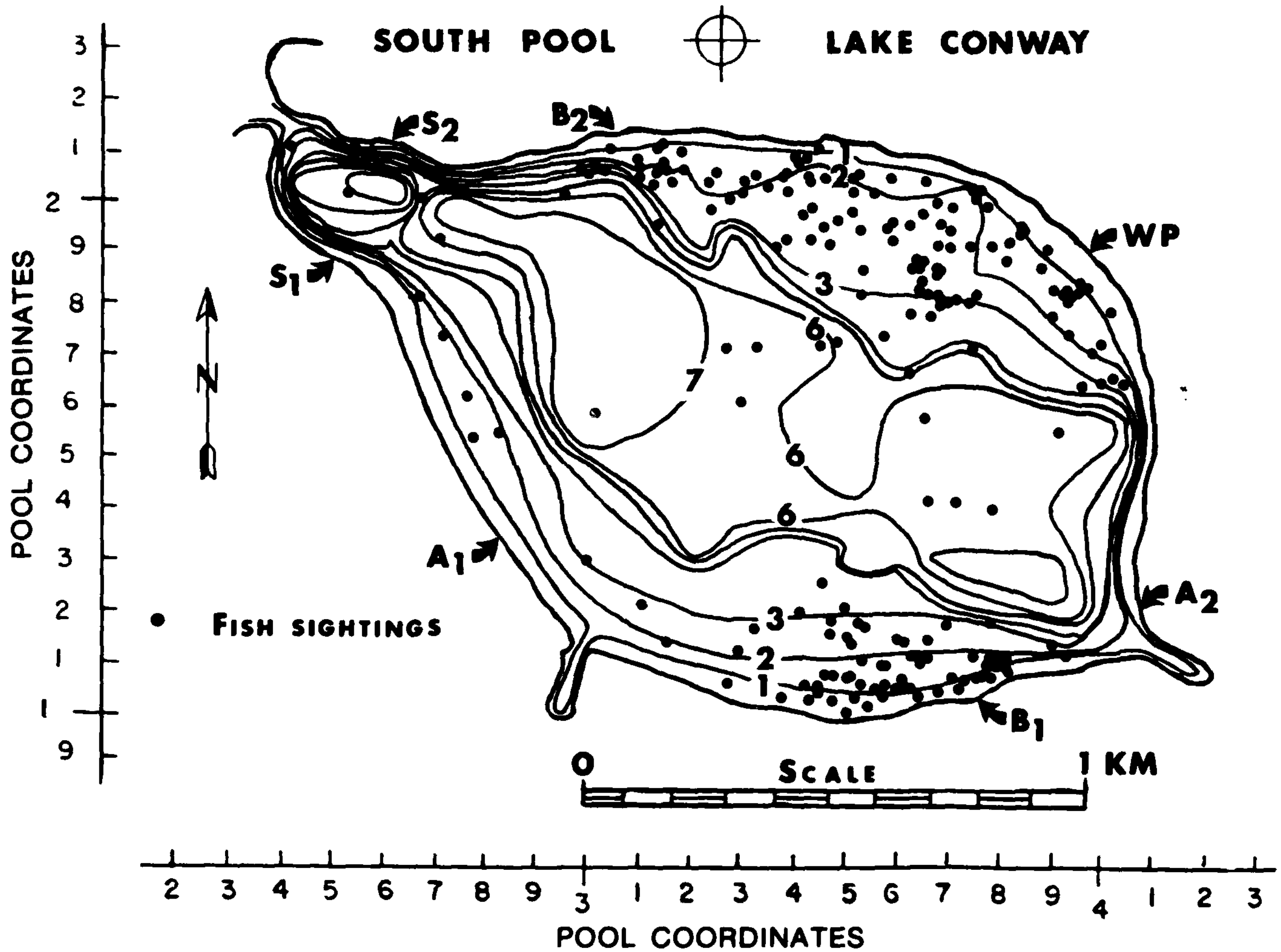

Figure 9. Cumulative sightings plotted on depth map (in metres), South Pool

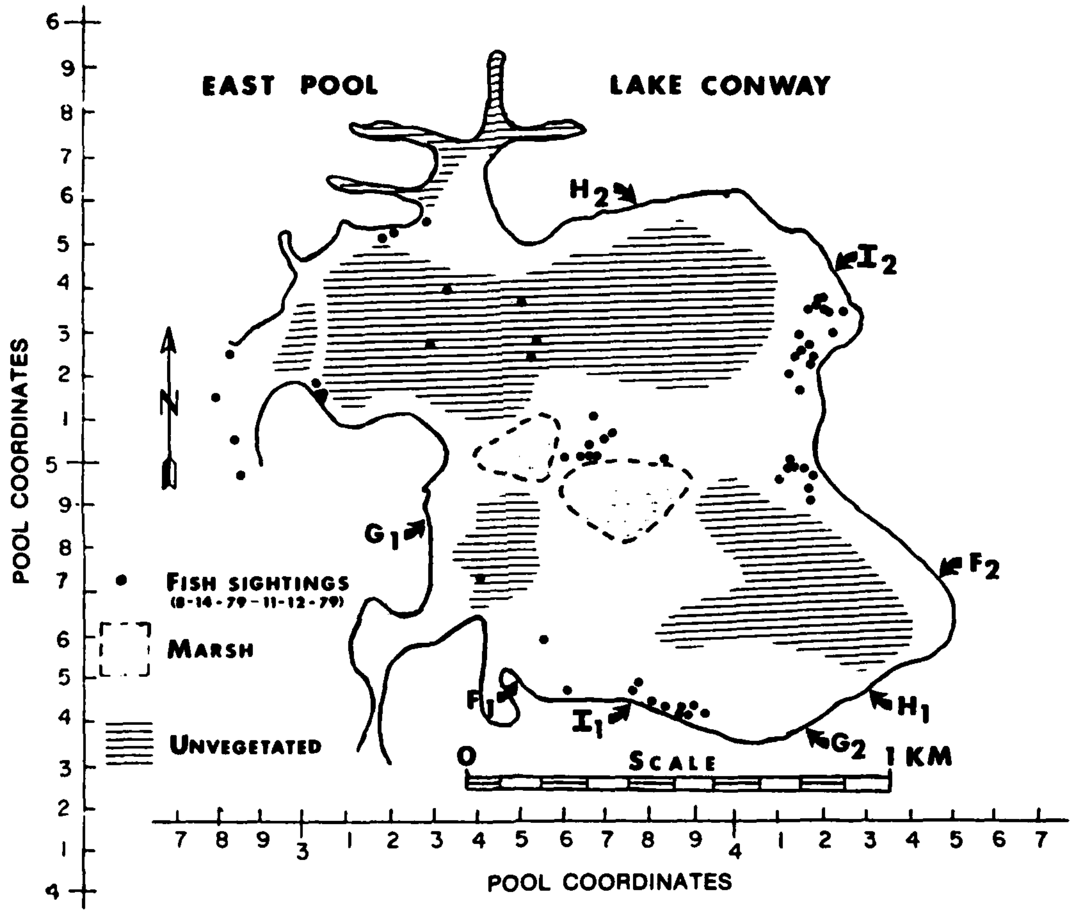

Figure 10. Cumulative sightings plotted on vegetation map, East Pool

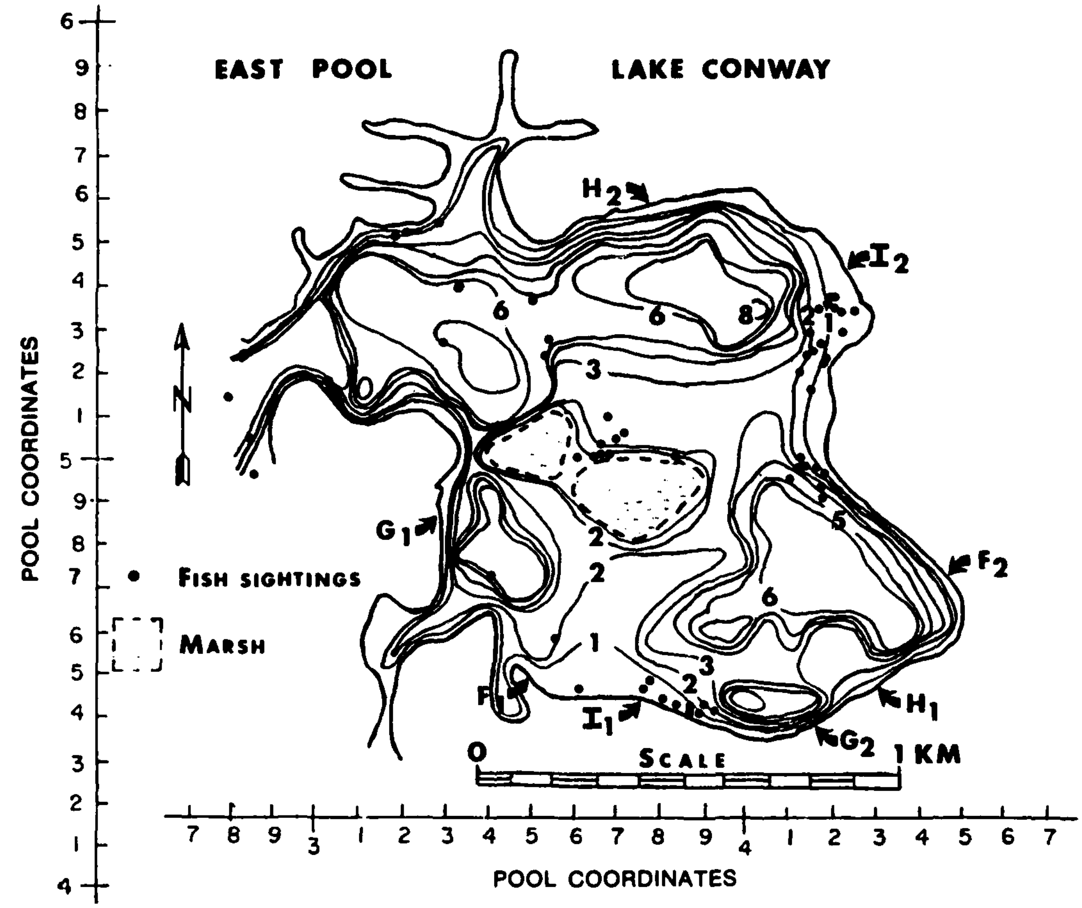

Figure 11. Cumulative sightings plotted on depth map (in metres), East Pool

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Appendix - Sequential Sightings of South Pool Fish

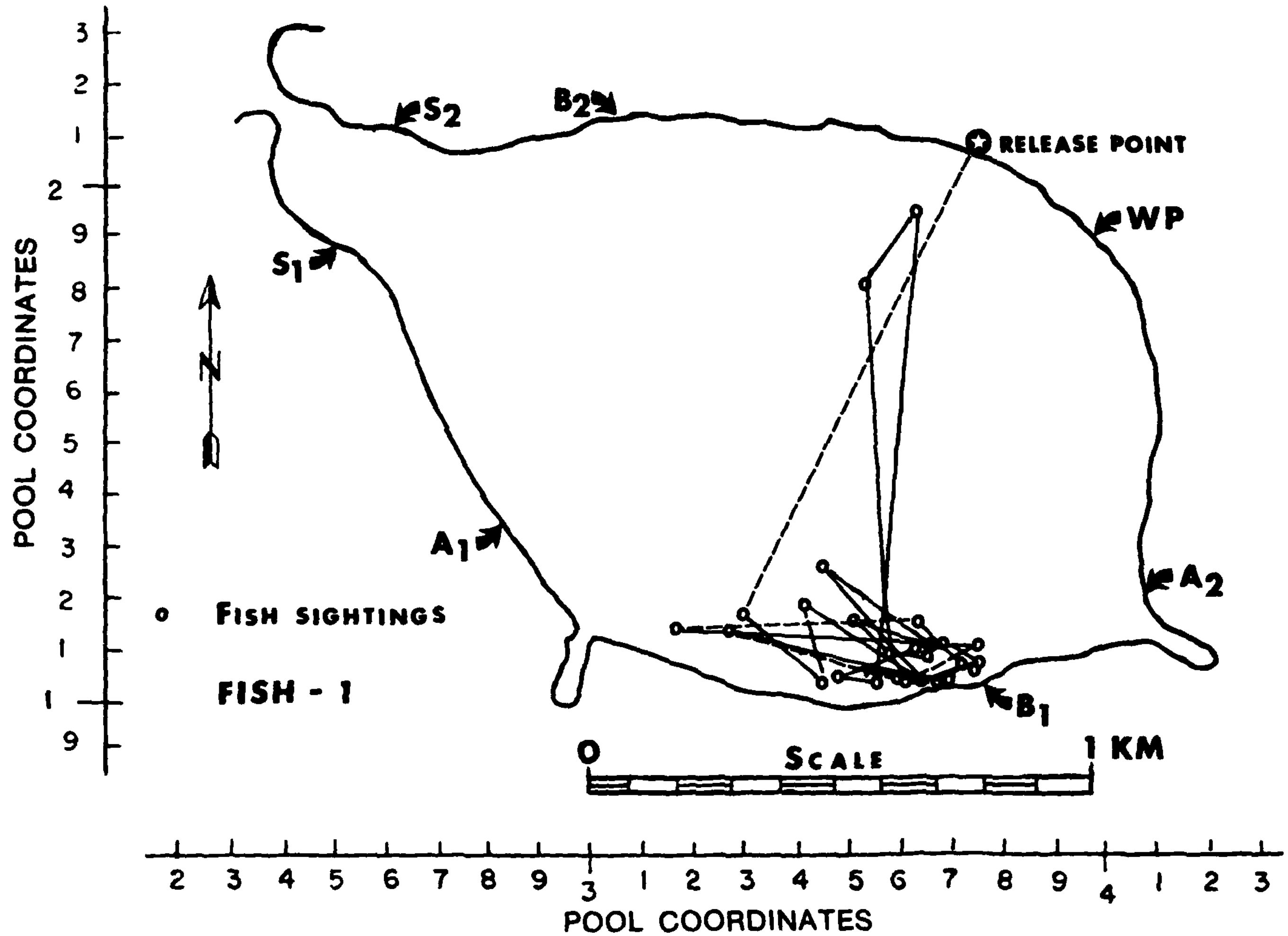

Figure A1. Sequential sightings for fish No. 1

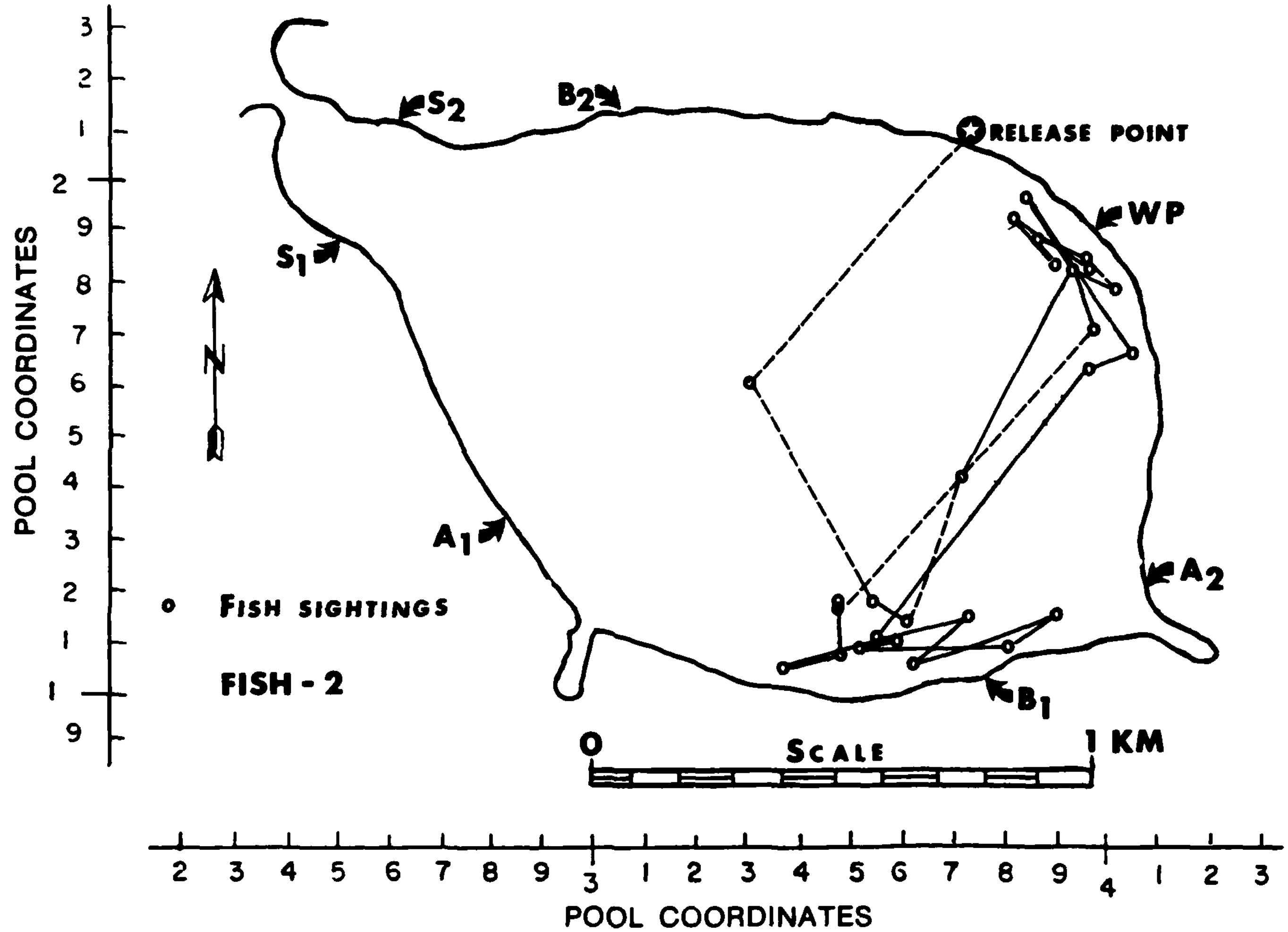

Figure A2. Sequential sightings for fish No. 2

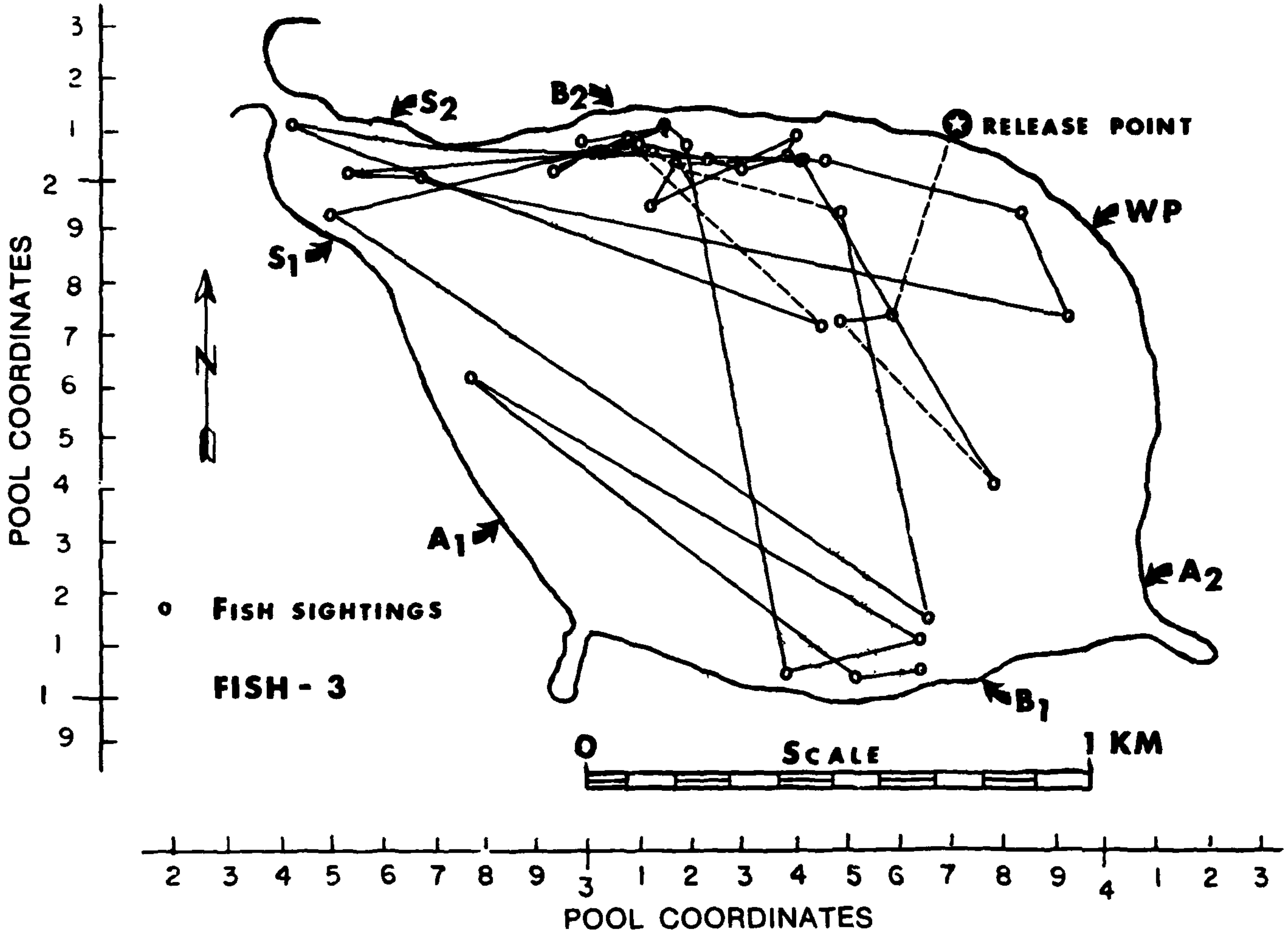

Figure A3. Sequential sightings for fish No. 3

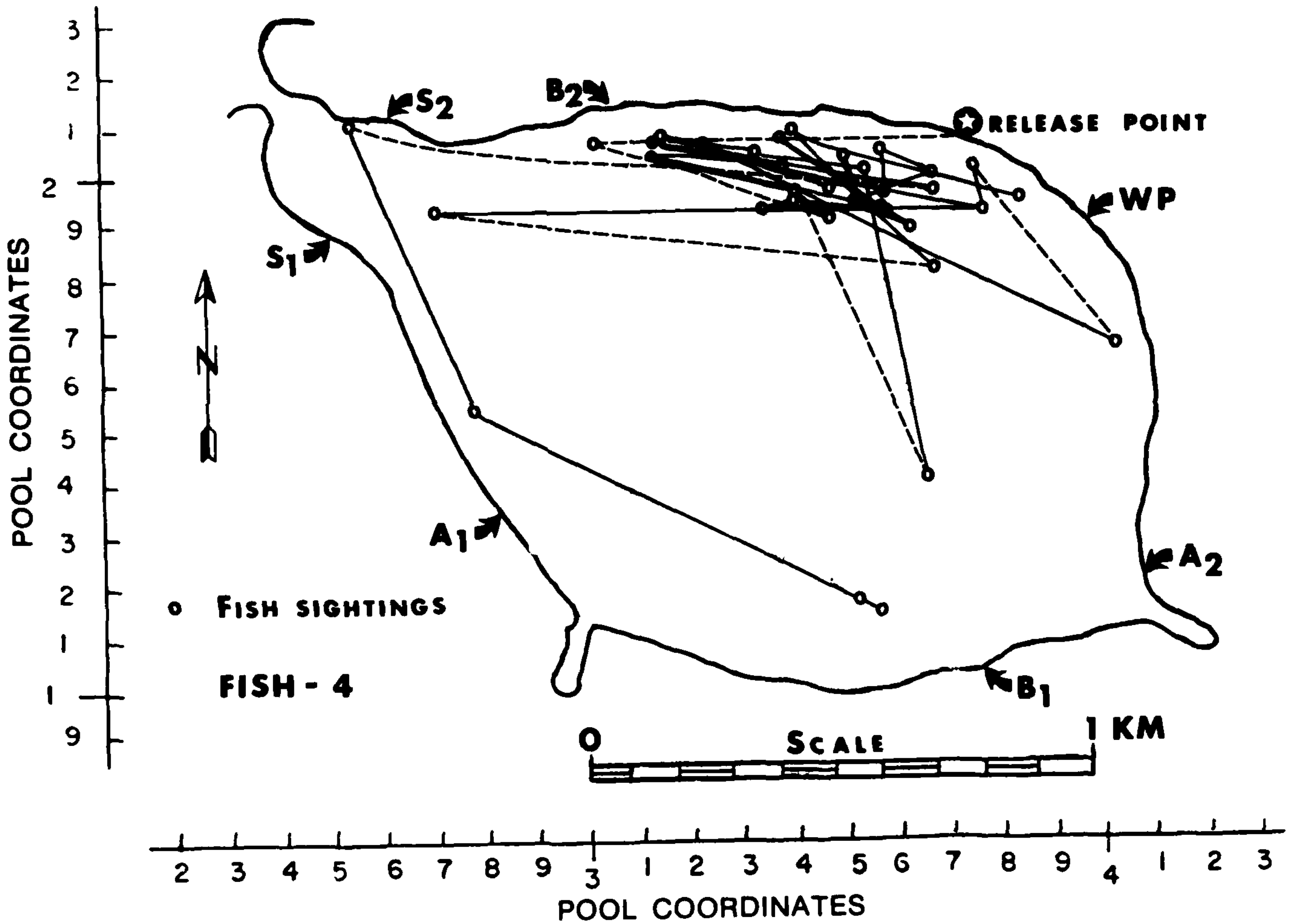

Figure A4. Sequential sightings for fish No. 4

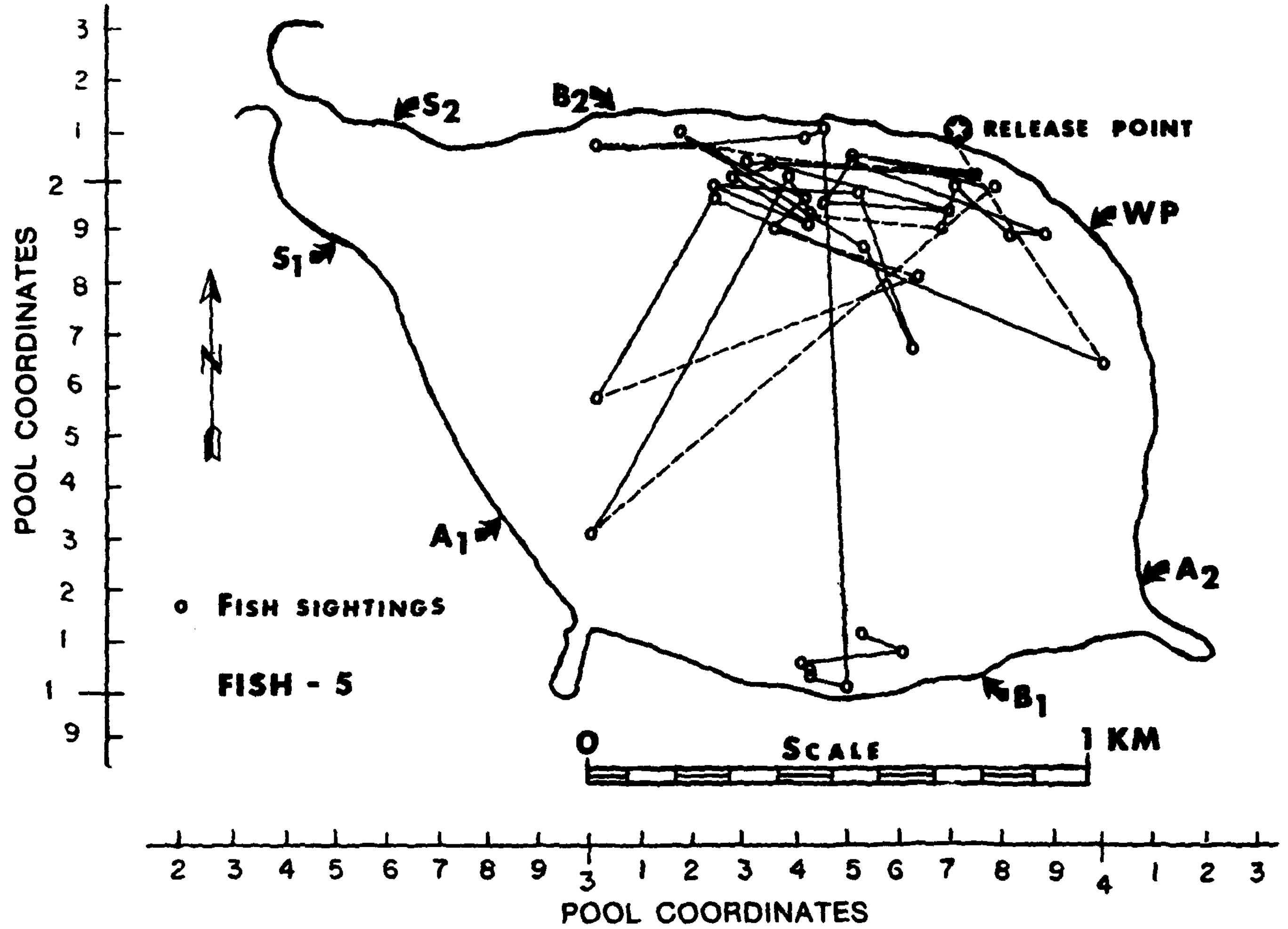

Figure A5. Sequential sightings for fish No. 5

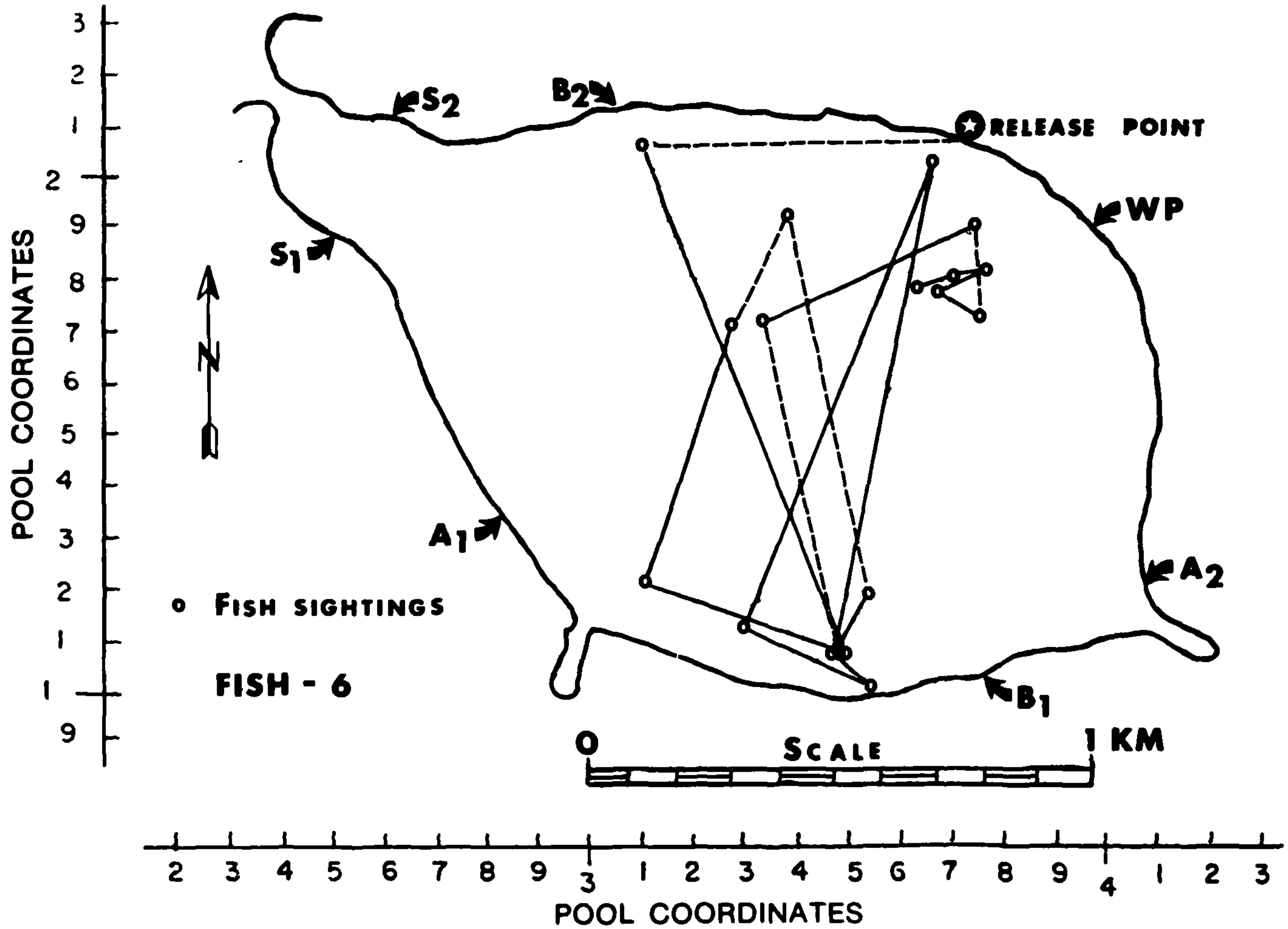

Figure A6. Sequential sightings for fish No. 6

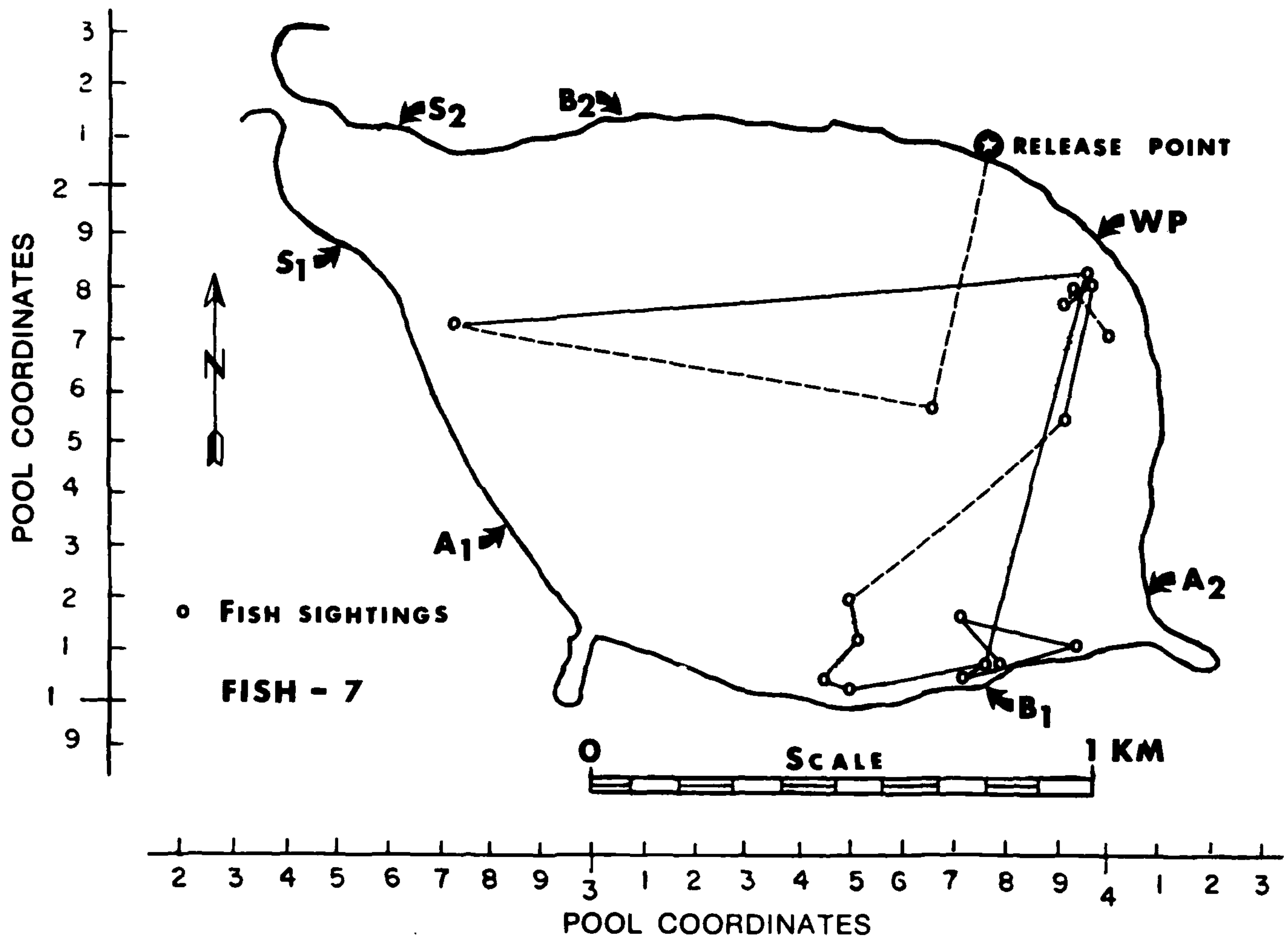

Figure A7. Sequential sightings for fish No. 7

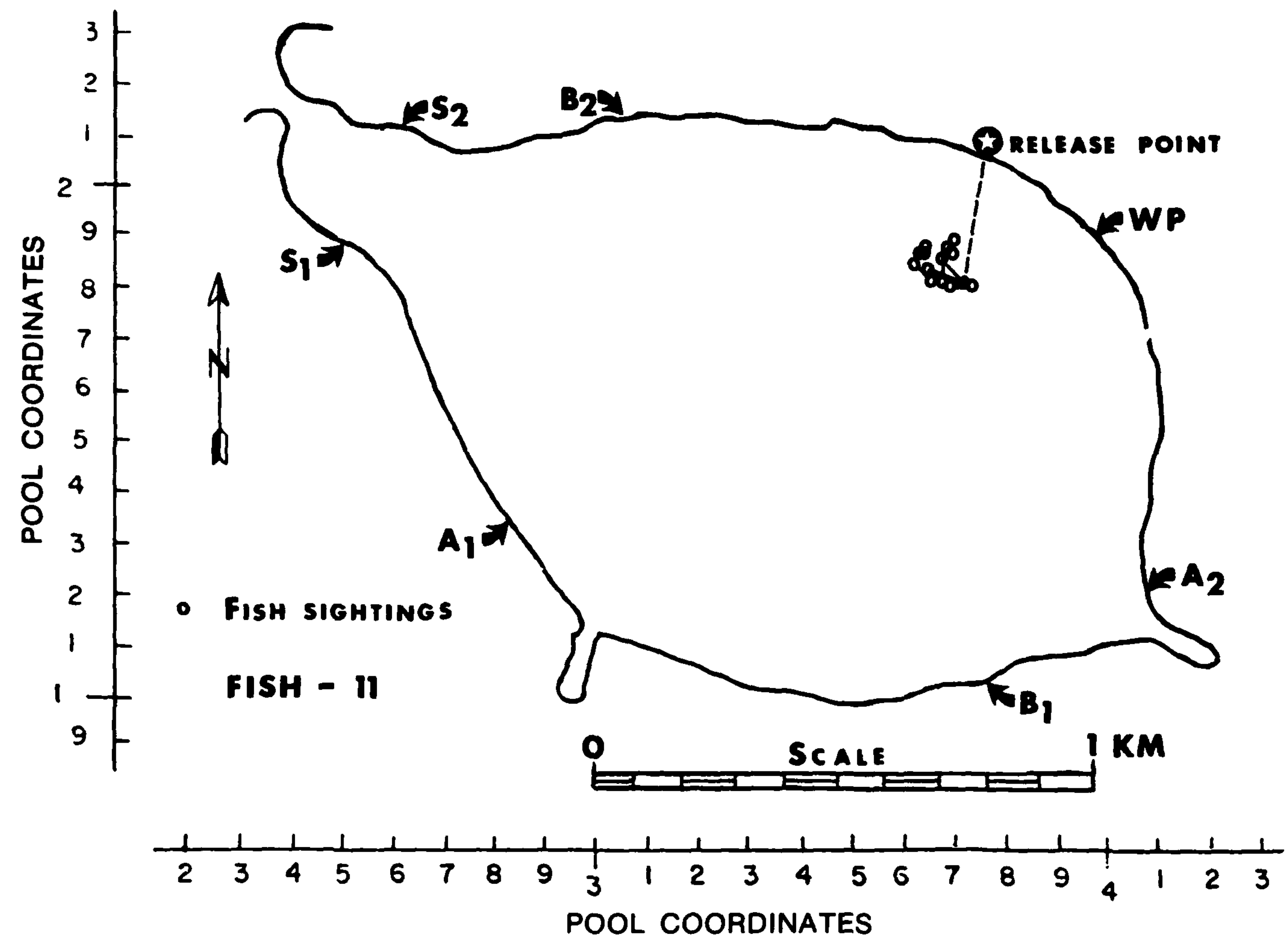

Figure A8. Sequential sightings for fish No. 11

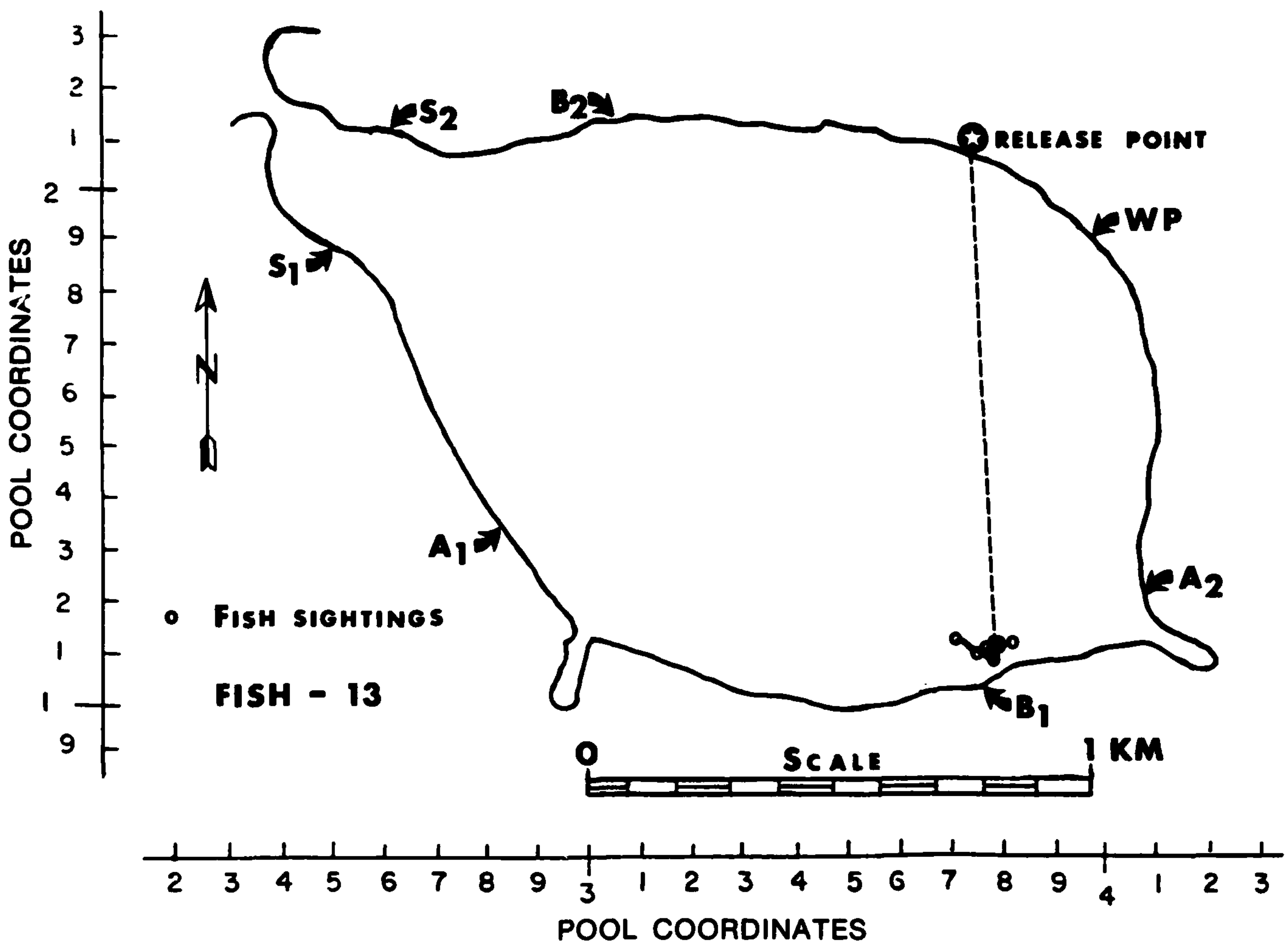

Figure A9. Sequential sightings for fish No. 13

LARGE-SCALE OPERATIONS MANAGEMENT TEST USING THE WHITE AMUR AT LAKE CONWAY, FLORIDA

Human Factors Study

by

Randall R. Williams*

Introduction

Basic scientific research stresses the control of as many independent variables as possible while systematically varying the dependent variables. However, this form of testing procedures is often not relevant to real world situations. Large-scale prototype testing has become an increasingly appropriate step between the confinement of the controlled laboratory setting and the variability of natural systems.

Such was the research status of the white amur prior to the Lake Conway LSOMT. To accurately assess the white amur as a management tool for controlling hydrilla, it was necessary to study the amur in a large aquatic system. Thus, the research began at Lake Conway in 1975.

As the Lake Conway test proceeded, investigators became increasingly conscious of the external uncontrolled variables that could be conflicting the results of this field test. It became obvious that a study was needed to investigate how human activity or acts of nature unrelated to the presence of white amur could obscure the impacts of the amur. A "Natural and Human Factor Study" was developed to document a wide variety of variables that might have immediate or long-range effects on water quality and/or abundance, distribution, and species composition of vegetation, fish, and wildlife of Lake Conway. It was hoped that the study would provide information to determine the proper reason for any change in the Lake Conway system occurring from 1975 until 1979. If the white amur was the causative agent, so be it; but if some other factor was involved, we did not want the white amur credited with, or blamed for, the change.

Scope

The scope of the Natural and Human Factors Study included:

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* U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

a. Definition of the boundaries of the study area with regard for focus on potential impacts.

b. Determination of population changes about Lake Conway.

c. Quantification of land-use changes in the study area.

d. Measurement of the extent of habitat changes.

e. Identification of changes in resource management strategies.

f. Documentation of factors affecting the physical or chemical condition of Lake Conway.

Methodology

A research plan was formulated after a review of literature and conduct of a series of exploratory interviews with the staff of appropriate agencies, or individuals either knowledgeable of the study or familiar with the study area.

From these preliminary interviews, it became apparent that information illustrating population changes and land-use changes was limited. The information base that was most correlative to 1975 through 1979 land-use changes about Lake Conway was the traffic zone information furnished by Orange County Planning Department. The six traffic zones that surround Lake Conway were chosen as the area for study. However, measurements and particular attention were directed to the shoreline and littoral zone. These two areas (traffic zones and shoreline) became the focal points for the study.*

Data Sources

Interviews

Our data sources consisted of interviews with 40 agency officials who work directly with pertinent Lake Conway data. Also, 10 long-term Lake Conway residents were interviewed for their ideas on changes that had occurred within the last 4 years.

Aerial photography

We analyzed all available aerial photography for land-use changes, residential growth, and vegetation changes. We also used the multispectral photo analyzer (System 100) at Kennedy Space Center to assist in identifying vegetation changes.

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* Orange County Planning Department, 1974-1979 Traffic Zone Section, Orlando, Florida.

Surveys

Various surveys were conducted throughout the study area. Observations were made last summer to supplement existing documents and confirm interview information. Specific survey objectives were made to obtain counts of area and shoreline homes, determine recreation patterns and intensity, determine ground truth for aerial photo analysis, and identify and document habitats.

Other data sources

Additional information was obtained from baseline and intermediate reports of LSOMT, Lake Conway; the Resources and Planning Act data tables of the U. S. Department of Agriculture Forest Service (Fort Collins); and the Habitat Evaluation Procedure handbooks and files from the Project Impact Evaluation groups of the Fish and Wildlife Service, U. S. Department of Interior (Fort Collins). Regular resource books were also used and are listed in the reference section.

Results

The data and results of the study will be published this spring. The remainder of this paper will present examples of observations that might be of interest to the interpretaion of data gathered by LSOMT Lake Conway contractors.

Population changes

In population growth, Orange County remains in the top 1 percent nationally. Since lakes naturally attract residents and are locales for recreational activities, Lake Conway, with its desirability for residential development, has had changes in land and water resource use.

Estimates of the changes in population from 1975-1979 in the study area (six traffic zones) indicate that about 15 percent more people now live in this area than did in 1975. This is an increase from 9,000 people in 1975 to 10,150 in 1978. Projections in 1978 for 1980 predict another 15 percent growth in the target area in just 2 years, which will bring the population to 11,250.

Land-use changes

Target area traffic zones. The total land area of the study area (comprised of the six traffic zones) is 930 ha. This value excludes the 717 ha of water surface. From 1975 to 1979, there was a land-use conversion of 140 ha of land. This represents a 16 percent change in land use. Most of this change represents loss of undeveloped natural land or agricultural land use (orange groves and pasture) to residential development.*

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* Orange County Planning Department, 1974-1979 Traffic Zone Section, Orlando, Florida.

Shoreline zone. From 1975 to 1979, there was a 10 percent change in shoreline and littoral zone vegetation. Most of this change was caused by the addition of 185 new shoreline homes. The trend is for natural vegetation to be cleared and replaced by beaches or lawn sod. A total of 2600 m of shoreline and littoral zone were drastically changed in this manner from 1975 through 1979. However, another 1100 m of shoreline was also developed from a natural vegetated state to a marginal residential form of land use (shrubs, uncut lawn grass, or vegetative regrowth areas).*

Habitat loss

A study was performed to estimate the loss of habitat caused by urban and residential changes mentioned previously. Particular information that was crucial for this study effort was identification and definition of habitat requirements for the known fish and wildlife species of Lake Conway. Our approach was to establish habitat suitability conditions. A habitat suitability condition can be defined as the conditions that support life by providing either feeding, resting, or nesting cover.

For each of the known species of Lake Conway, a list of life support requirements was made resulting in the compilation of habitat requirement data for each species.

To better estimate the loss of habitats and the cause of the loss, 60 habitat suitability conditions were condensed into five general land-use categories. These broad categories are:

a. Natural undeveloped areas.

b. Marginal natural areas intermixed with residential developement.

c. Agricultural land use.

d. Extreme developed areas.

e. Open water.

From the aforementioned data, a quantifiable habitat benefit unit was derived by totaling the number of species that require a particular habitat multiplied by the number of life support conditions (food, resting, or nesting cover) it may provide.

This quantifiable habitat benefit unit was used as a basis for estimating values for loss due to land-use changes. Changes in habitat provisions were then estimated for the various species groups of mammals, birds, fish, and herpetofauna of Lake Conway.

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* Ibid.
Some figures were derived from studies by the East Central Florida Regional Planning Council, Winter Park, Florida, 1979. Florida Department of Transportation Topographic Office, Aerial Photography Section, Tallahassee, Florida.

Resultant percentage of habitat loss in the target area and around the shoreline (1974-1978) is listed below:

Species	Target Zone Percent Loss	Shoreline Area Percent Loss
Mammals	17	11
Birds	15	10
Herpetofauna	10	9
Fish		1

These values are felt to be conservative or less than actual loss due to (a) the broad definition of habitat suitability conditions, (b) the interpretation of aerial photography, (c) the overlap of broad land-use categories, and (d) the ecological bias that, although habitat conditions were available, the area of habitat often was minute and clustered with much spacing caused by urbanization.

Water quality

Storm water runoff is a serious threat to lake water quality in Orange County. The rapid population growth has caused much of the riparian area to be roofed or paved over. This urbanization of the watershed has greatly reduced the infiltration rates of the in situ soils. The deep sand native soils on nearly level slopes has caused infiltration to be immediate and complete.

Because of this rapid infiltration, the water table averages from 120 to 150 cm. Earlier work by Blancher (1979) and Fellows (1978) indicates that 7.6 cm of rainfall is necessary before any surface runoff can be detected. Estimation of total runoff in the Lake Conway system shows an increase from 1973 to 1974 of 11 percent and, in 1975, to 14 percent.

The problems of storm water runoff in Lake Conway prompted the Board of County Commissioners, Orange County, and the Lake Conway Navigation and Advisory Board to retain the firm of Canin/Miller Associates to study storm water pollution of the lake complex. Their report (1978) listed over 50 existing storm water pollution discharges into Lake Conway. Also, in 1978, a storm water detention facility was constructed to treat runoff from one of these 50 discharges instead of direct pipe discharge into the lake. This one structure, during the rainy season of 1978, prevented 220 lb of trash and debris, 33 tons (dry weight) of sediment, and approximately 2400 lb of plant biomass from entering the lake. Sediment analysis indicates that 60 lb of phosphorus, 174 lb of nitrogen, and 4200 lb of chemical oxygen demand have been prevented from entering the lake system by this one structure.*

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* Interview with Joseph M. Mele, P. E., Orange County Engineering Department, Public Work, 2 July 1979, Orlando, Florida.

Seepage, as determined by Fellows (1978), provides another cultural eutrophication problem. Via seepage, 6 to 12 percent of all nitrate fertilizer applied along the shoreline has been determined to enter into the lake. Approximately 75 percent of the residents about Lake Conway use septic tanks with absorption fields.* The soil types around Lake Conway are highly permeable, allowing the water table to rise into the septic fields or allowing the leachate from the septic fields to pollute the groundwater and lake water. Another problem with this form of sanitation is that most residents shunt the gray water directly into the soil and some are highly suspected of routing this very nutrative wastewater into the lake via submerged pipes. A review of the complaints registered by lakeshore residents with the Orange County Pollution Control Department substantiated the previously mentioned water quality perturbations. These complaints consisted of five major categories: dredge and fill activities (39); algae (11); fish kills (10); canal problems (9); and white foam (7).*

The survey of the 10 residents also aided further in documenting the earlier findings that water quality of the lakes has gradually deteriorated. Residents were also concerned about the steady decrease of natural habitat and increased recreational usage. Our recreation survey revealed, however, that the lakes appear to be well within normal use ranges for comparable bodies of water.

Conclusions

The results of this study, when used in conjunction with contractors' reports from the LSOMT Lake Conway study, will allow WES scientists and engineers to accurately and confidently assess the effects of the white amur and, solely, the effects of the white amur.

Therefore, the management capability for the white amur as an aquatic plant control tool can be successfully evaluated in natural systems where its use is much needed.

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* Orange County Pollution Control Department, Department Files, 1975-1979, Orlando, Florida.

References

Blancher, E. C. 1979. "Lake Conway, Florida: Nutrient Dynamics, Trophic State, Zooplankton Relationships." PhD Dissertation, College of Engineering, University of Florida, Gainesville, Florida.

Canin/Miller Associates. 1978. "Lake Conway Canal Improvement and Pollution Control Program." Orlando, Florida.

Fellows, C. R. 1978. "The Significance of Seepage in the Water and Nutrient Budgets of Selected Florida Lakes," MS Thesis, College of Engineering, University of Florida, Gainesville, Florida.

LARGE-SCALE OPERATIONS MANAGEMENT TEST USING THE
WHITE AMUR AT LAKE CONWAY, FLORIDA

Use of a Recording Fathometer for Determining Distribution and Biomass of Hydrilla

by

Michael J. Maceina* and Jerome V. Shireman*

Introduction

Uncontrolled growth of aquatic vegetation can alter both the abundance and well being of fish populations, limit recreational use, create health hazards, and block navigation and irrigation routes. The introduction and spread of exotic aquatic plants and increased nutrient levels, particularly in urban and agricultural areas, have greatly compounded the problem. It becomes necessary, therefore, to control these plants if a water body is to be utilized to its fullest extent. Haller (1977)** lists four basic types of control that include: (1) mechanical harvesting, (2) chemical herbicides, (3) biological control agents, and (4) physical control by water level manipulation.

Research efforts continue to examine, formulate, and improve weed control methods, while considering positive and/or adverse impact of these control methods on the entire aquatic system. In order to determine and evaluate control methods, quantitative and qualitative data pertaining to plant communities are needed.

The purpose of this research project was to investigate the potential of a recording fathometer for conducting vegetation surveys. The use of this instrument could possibly save time, labor, and capital equipment outlays.

Objectives

The objectives of this project were to:

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* University of Florida, Gainesville, Florida.
** Haller, W. T. 1977. Hydrilla - a new and rapidly spreading aquatic weed problem. Agricultural Experiment Station/IFAS Cir. S-245. University of Florida, Gainesville, Florida. 13 pages.

a. Evaluate the use of a recording fathometer as a means of conducting vegetation surveys.

b. Develop procedures to estimate plant biomass from fathometer recordings and record vegetation changes that occur during the study period.

c. Develop quantitative vegetation parameters that describe lake vegetation.

Materials and Methods

A DE-719 precision Survey Fathometer (Raytheon Marine Co., Manchester, N. Y.) was utilized for all vegetation surveys (Figure 1) conducted on two central Florida lakes (Lake Baldwin and Lake Wales) from May 1978 through March 1979. An extendable bracket to house the transducer was permanently mounted on the transom of a 4.9-m, aluminum, flat-bottomed boat powered by a 20-hp outboard motor (Figure 2). The transducer was mounted at a 14-1/4-deg angle above the horizontal to facilitate improved echo depth sounding reception while the boat was moving. The transducer was mounted so that the bottom of the boat was even with the bottom face of the transducer making the apparatus "weedless." A marine 12-V battery supplied power to the fathometer. Calibration procedures were according to the instructions outlined by the manufacturer (Raytheon Marine Co., 1972).

A fathometer works on the principle of echo depth sounding by computing the time interval required for sound waves to travel at a known velocity from a known point to a reflecting surface and return. The precise water depth is calculated by multiplying one half the time interval by the velocity of sound in water. Hard bottoms such as sand and rock provide the best reflective surface for sound waves, producing sharp and clear images on chart paper. Aquatic weeds have a lower specific density and generally cause weaker reflections; therefore, tracing patterns are not as clear and defined.

The DE-719 is a lightweight (21.3 kg) portable recording fathometer that can be mounted temporarily or permanently. The recorder provides a detailed chart tracing pattern of underwater topography in depths between 0.7 and 125.0 m (Figure 3). Depths are accurate over this range to $\pm$0.5 percent. The DE-719 is well suited for freshwater vegetation surveys providing high resolution recordings due to the narrow transducer beam width, high sounding rate, rapid chart speed, and high signal frequency. Operating frequency is 200 Hz.

Bottom depth readings were consistently accurate to within 0.1 m of the true depth when calibrated with a weighted sounding line. Adjustment to true depth was made by slightly altering the speed of sound control, which is located inside the machine. Highest sensitivity was achieved by setting the sensitivity on-off control dial to its highest position and utilizing a chart speed of 10.16 cm/min. Metric chart paper was used during all surveys.

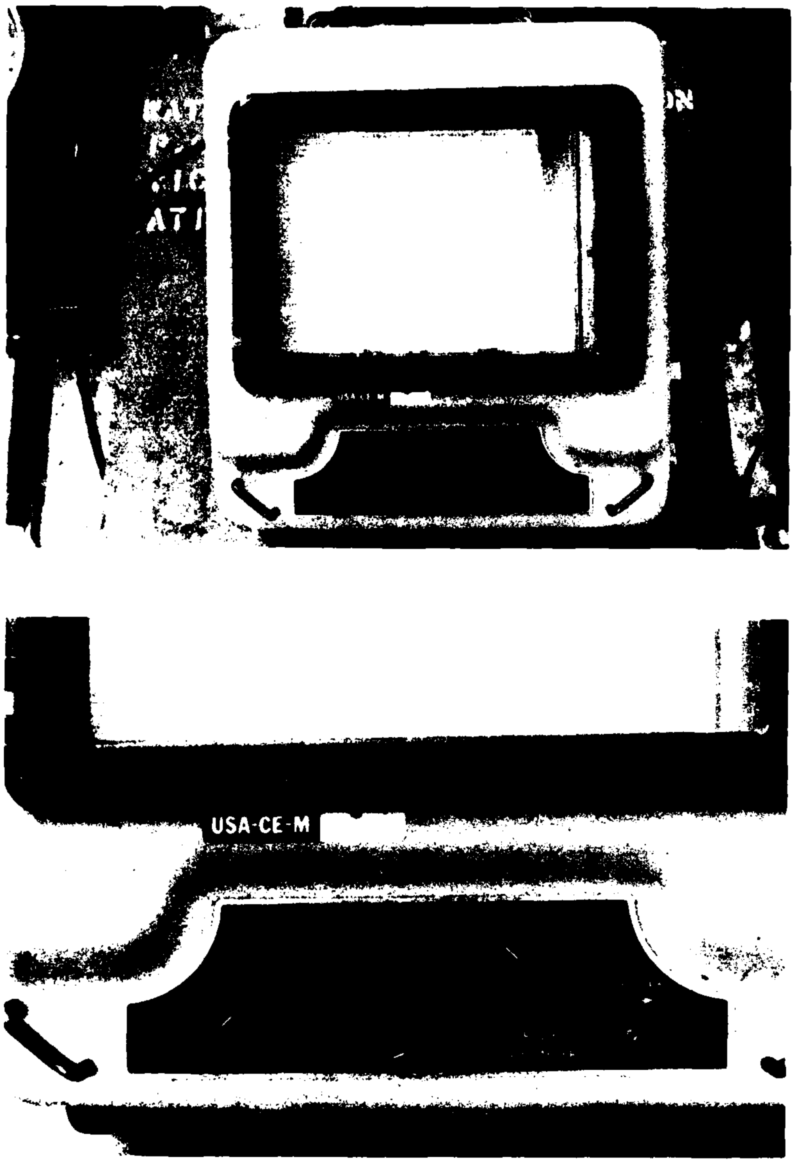

Figure 1. DE-719 recording fathometer

Figure 2. Fathometer transducer and bracket attached to the boat

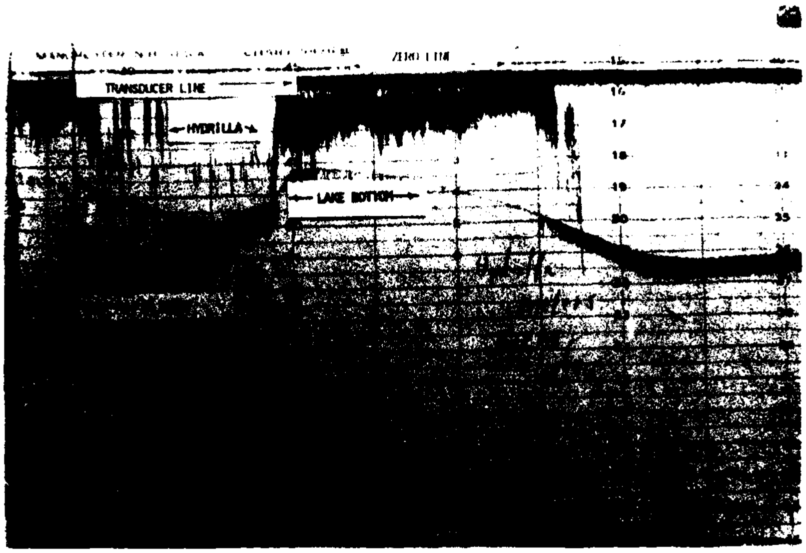

Figure 3. A section of chart tracing recorded from Lake Baldwin showing start of transect, lake bottom, and hydrilla infestation. Note the tall stand of hydrilla merging with the transducer line

Recent aerial photographs were obtained for each study lake. Permanent landmarks were obtained from these photographs and transects were conducted by traversing the lake from one landmark to another across the lake. Referral to the aerial photographs allowed for exact transect location.

To conduct a transect, the following procedure was followed. After calibration, the fathometer was switched on and the on-off sensitivity dial set to the highest sensitivity. The boat was backed slowly to the edge of the lake and aligned between the starting point landmark and the landmark across the lake. The boat was quickly accelerated to a speed of 2 to 3 m/sec (4 to 5 knots). After boat speed was stabilized, a fix mark was placed on the chart paper by engaging the fix mark switch. The boat was driven across the lake towards the chosen landmark maintaining a constant speed by adjusting the speed control on the motor throttle. During this time, field observations of vegetation conditions, transect number, lake, and date were written directly on the chart paper with pencil. Within 10 m of the opposite bank, emergent vegetation, or other structure, another fix mark was placed on the chart designating the end of transect. The outboard motor was quickly shifted into reverse to stop the boat. The fathometer was turned off and the boat was driven to another point on the shoreline to start the next transect. With experience, one man could operate both the outboard motor and the fathometer at the same time. Bathymetric maps were constructed for each study lake.

Differentiation of various submersed macrophytes from tracings was accomplished by dropping a buoy over the side of the boat marking an unknown vegetation community while transects were being conducted. A corresponding fix mark was placed on the chart marking the buoy position. Upon completion of a transect, a weighted dredge was lowered at each buoy and vegetation was collected for identification.

Hydrilla biomass was correlated with fathometer tracings to estimate total hydrilla standing crop in Lake Baldwin. While monthly transects were being conducted during August and December 1978 and March 1979, weighted numbered buoys were dropped to mark sampling stations. Simultaneously, corresponding fix marks were placed on the chart paper and the number of the buoy was recorded on the paper. The following day, a circular core biomass vegetation sampler was used to take replicate 0.257-m^2 samples at each buoy (Figure 4). Samples collected with the biomass sampler were washed and shaken in a nylon net to remove excess sand, mud, and water and weighed to the nearest 5 g on a platform scale. Wet weights were later converted to kilograms per metre for analysis. A total of 202 samples were collected on these three dates at depths varying from 1.7 to 6.2 m and in different hydrilla densities.

Fourteen vegetation transects totaling 11.32 km in distance were conducted monthly on Lake Baldwin from May 1978 to March 1979 (Figure 5). Sixteen transects, 13.24 km in distance, were run in Lake Wales, Florida, during May, August, and November 1978 and in February 1979.

Figure 4. Core biomass sampler used to collect biomass samples from Lake Baldwin

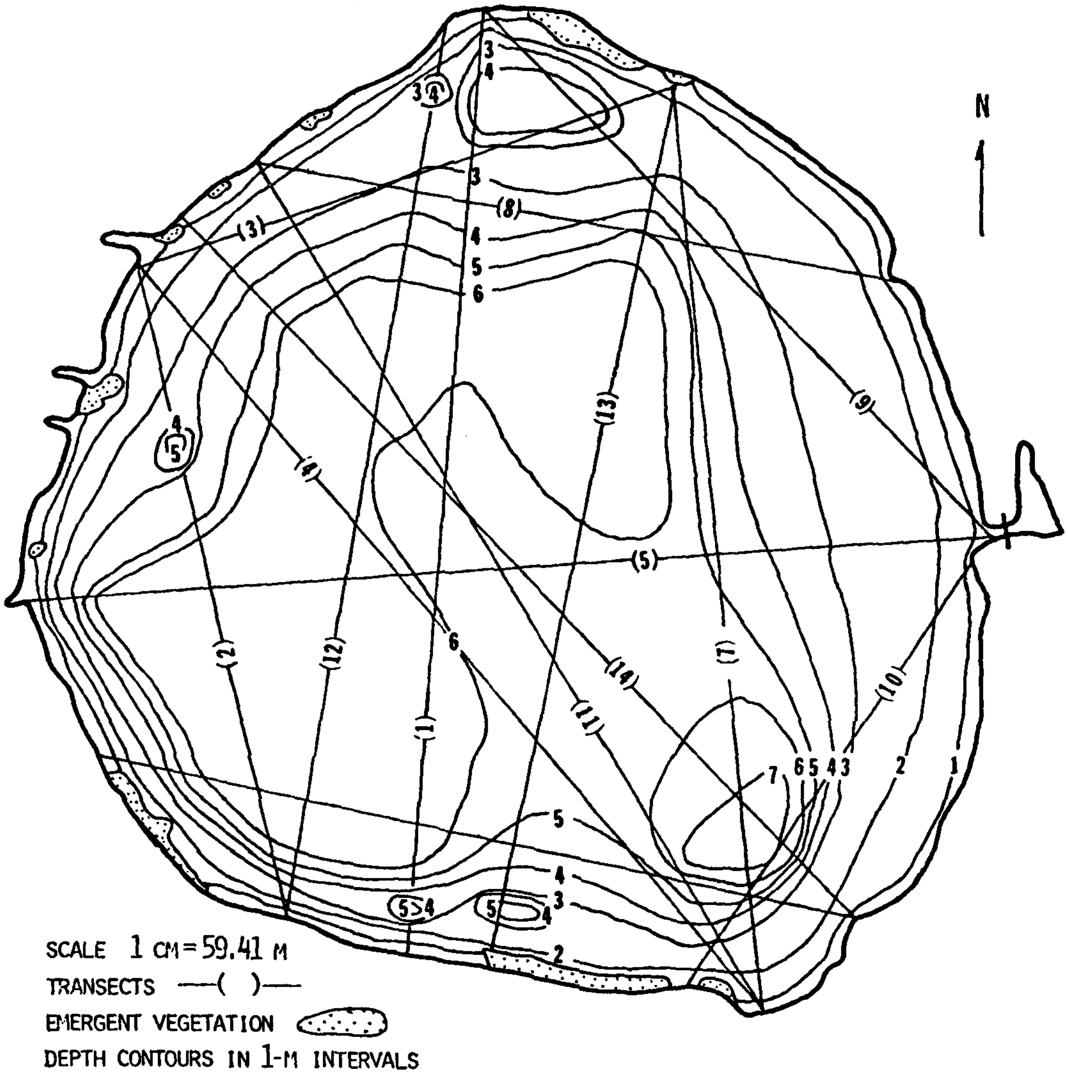

Figure 5. Depth contours and transect lines, Lake Baldwin, Florida

Techniques and Results

Differentiation of submersed macrophytes

During the study, hydrilla was the only submersed macrophyte found growing in Lake Baldwin. Separation of vegetation communities by species did not occur. In Lake Wales, eelgrass beds were found growing at depths to 3.0 m and did not reach a height greater than 0.7 m from the hydrosoil. During the late spring, summer, and fall hydrilla could be differentiated from eelgrass simply by examining differences in vegetation height on the chart tracing (Figure 6). Typically, hydrilla was

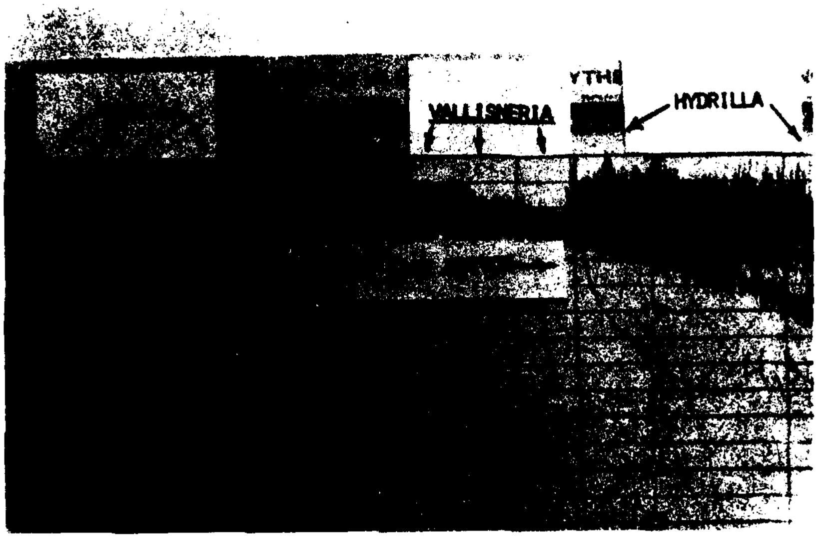

Figure 6. Section of a transect as recorded by the fathometer, Lake Wales, Florida, illustrating stands of *Vallisneria* and *Hydrilla*

found growing taller than eelgrass. In some cases examination of fathometer tracings revealed that hydrilla patterns were denser near the top of the plant, whereas eelgrass patterns were less dense and more evenly distributed. According to Haller and Sutton (1975)* the major portion of the biomass production in hydrilla is located in the upper portion of the plant, whereas in eelgrass biomass is more evenly distributed. This accounts for the differences in tracing patterns. Evenly mixed stands of hydrilla and eelgrass appeared as pure stands of

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* Haller, W. T., and D. L. Sutton. 1975. Growth and competition between hydrilla and vallisneria communities. Hyacinth Contr. J. 13:48-50.

hydrilla on the tracing. When eelgrass dominated, tracing patterns were characteristic of pure stands of this plant.

A lake adjacent to Lake Baldwin, Lake Susannah, was utilized to further test the detection of submersed macrophyte species by characteristic and distinctive tracing patterns. Filamentous blue-green algae *Lyngbya* sp. characteristically grows 0.1 to 0.2 m in height above the hydrosoil and was recorded as a low flat mound. The tracing is similar in pattern density to the hydrosoil (Figure 7). During the

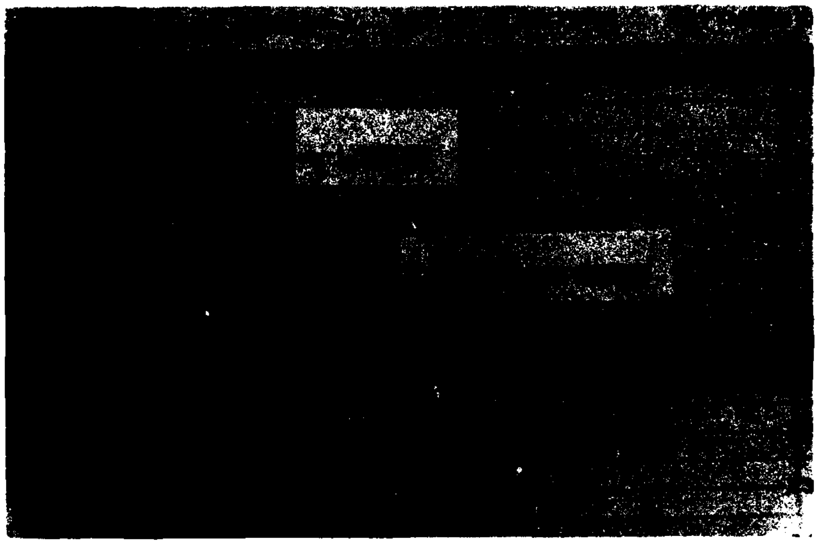


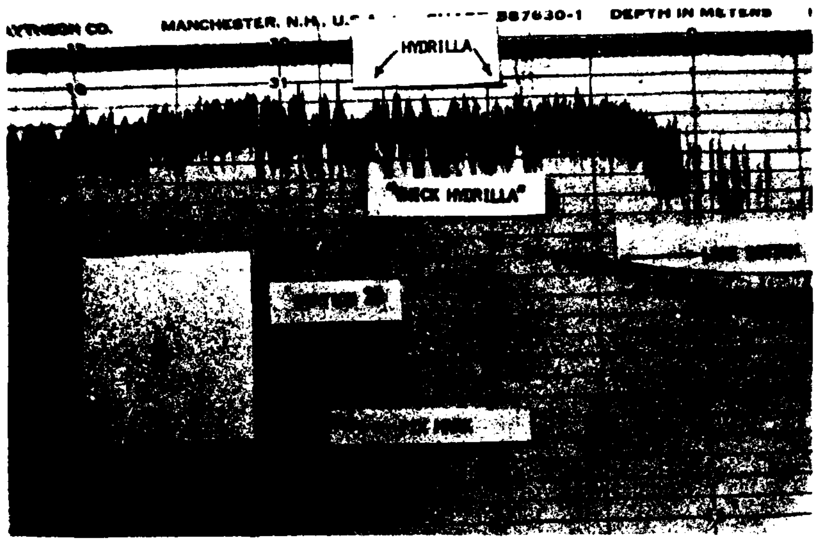
Figure 7. Section of transect recording in Lake Susannah, Florida, illustrating filamentous blue-green algae, *Lyngbya* sp.

summer and fall months, this pattern was distinguishable from all other types of submersed macrophytes in the lake. Hydrilla, southern naiad, *Nitella*, and *Chara* were sampled in different areas; however, differences in tracing patterns could not be detected. During the winter when submersed vegetation was near the bottom, *Lyngbya* could not be differentiated from the other macrophytes by tracing patterns.

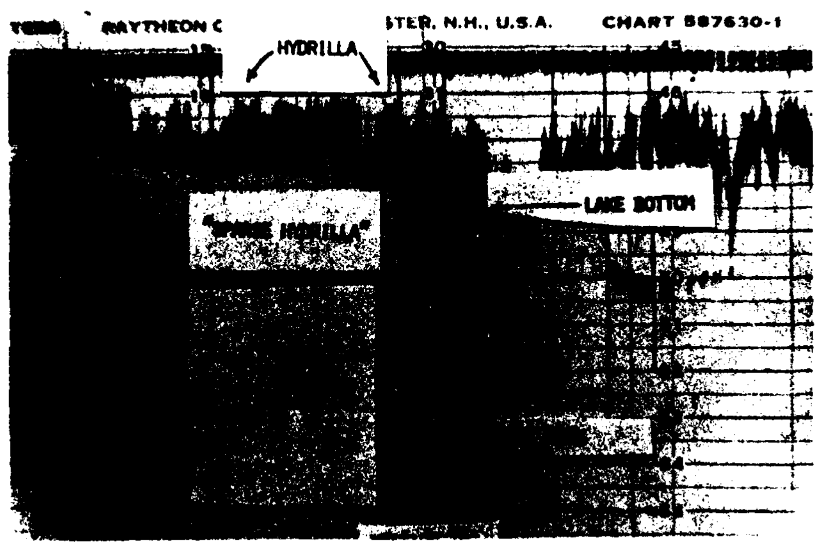
Correlation and prediction of hydrilla biomass utilizing chart tracings

Biomass data collected from August and December 1978 and March 1979 were used for analysis and model building. Two models correlating hydrilla biomass with fathometer tracings were based on tracing pattern characteristics. The first model, thick hydrilla, was indicated by sampling stations where dense and thick hydrilla did not permit a clear reading of the lake bottom (Figure 8a). The high hydrilla density prevented sound waves from penetrating and/or reflecting back to the

transducer through the plants. A second model, sparse hydrilla, permitted a clear reading of the lake bottom due to sparse and/or shallow hydrilla stands (Figure 8b).



a. Thick hydrilla biomass sampling station



b. Sparse hydrilla biomass sampling station

Figure 8. Sections of chart tracings along vegetation transects in Lake Baldwin

For thick hydrilla, the following multiple regression was found to be the best fitting ($R^2 = 0.796$) and highest probable model ($P < 0.01$) relating thick hydrilla biomass with tracing characteristics:

$$Y = 1.977 + 1.029X_1 - 1.341\ (\ln X_2) \qquad (1)$$

where

Y = wet weight of hydrilla, kg/sq m

X_1 = height of hydrilla from the hydrosoil to the top of the plant along the fix mark, m

X_2 = distance from the top of the hydrilla plant to the surface of the water along the fix mark, m

For sparse hydrilla, the following multiple regression equation was determined to be the best fitting ($R^2 = 0.807$) and highest probable model ($P < 0.01$) relating sparse hydrilla biomass with tracing characteristics:

$$\ln Y = -5.099 + 0.982\ (\ln X_1) + 1.301\ (\ln X_2) - 0.281\ (\ln X_3) \qquad (2)$$

where

Y = wet weight of hydrilla, kg/sq m

X_1 = hydrilla height from the hydrosoil to the top of the plant along the fix mark, m

X_2 = vertical cover of hydrilla on the tracing, percent

X_3 = distance from the top of the hydrilla plant to the surface of the water along the fix mark, m

Comparison of fathometer and direct biomass sampling methods

In order to evaluate the total hydrilla standing crop estimate generated by utilizing fathometer tracings, hydrilla standing crop was also determined by the method reported by Nall and Schardt (1978).*

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* Nall, L. E., and J. D. Schardt. 1978. Large-scale operations management test of use of the white amur for control of problem aquatic plants. Report 1, Baseline studies, Volume 1, The aquatic macrophytes of Lake Conway, Florida. Technical Report A-78-2. U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

On 8 March 1979, following collection of replicate hydrilla biomass samples to correlate biomass with chart tracings, 100 random biomass samples were taken utilizing the core vegetation sampler. A map of Lake Baldwin was constructed and a grid pattern overlaid with two hundred 0.4-ha (1-acre) blocks. One hundred blocks were randomly selected for sampling from a random numbers table. At each sampling site, water depth was measured and recorded. Hydrilla samples were washed and shaken to remove excess sand, mud, and water and weighed to the nearest 5 g. Weights were converted to kilograms per square metre for analysis.

Analysis of the direct random biomass sampling method determined a mean value of 1.21 $\pm$ 0.23 kg wet hydrilla/m^2 ($\pm$ 0.05 percent) (Table 1). Total standing crop was calculated and found to be 0.95 $\pm$ 0.18 million kilograms hydrilla for the entire lake. The estimated mean biomass calculated from fathometer tracings was slightly lower, 1.04 kg hydrilla/m^2. These two means were not statistically tested due to the different collection methods utilized and derivation of variances, but the occurrence of overlapping confidence intervals exhibited by each mean might indicate that the mean values were not significantly different. However, the fathometer biomass estimate was generated from those areas containing only hydrilla or for 70.5 percent of the area of the lake. The biomass estimate generated from direct random sampling was calculated for the entire area of the lake including those areas with and without stands of hydrilla. Of the 100 biomass samples collected, only 14 samples contained no hydrilla. These observations were calculated into the mean and confidence interval values which reduced the estimate. However, total standing crop estimates were observed to be much larger for the direct random biomass sampling (946,640 kg) than the estimate calculated from fathometer tracings (576,800 kg). Because the confidence intervals did not overlap, it is likely that these values are significantly different.

Inspection of the data revealed reasons for this discrepancy. Data from the direct random biomass sampling method indicated that hydrilla was inhabiting 86 percent of the lake. Fathometer tracings revealed only 71 percent of the lake area contained hydrilla. We feel that the 71 percent coverage figure calculated for the lake is more accurate due to the high number of transects conducted (14) and the total distance covered by these transects (11.32 km). Therefore, calculation of mean hydrilla biomass and total hydrilla standing crop values from the direct random biomass sampling data overestimated the amount of hydrilla in the lake due to the number of samples taken in hydrilla.

Closer inspection of the data revealed this source of error. Of the 100 samples collected by the direct random sampling method, only 4 percent were taken in water depths greater than 6.1 m. However, depth interval area values for Lake Baldwin demonstrate that 28.0 percent of the lake area is greater than 6 m in depth. The random sampling method underestimated the amount of sampling required in this portion of the lake. This method, though, placed the remaining 96 percent of the sampling effort in water depths less than 6 m, while actually 72 percent of the lake area is less than 6 m. Only 3 percent of the lake area

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Table 1

Comparison of Fathometer and Direct Random Biomass Sampling Methods for Hydrilla Biomass and Total Hydrilla Standing Crop for Lake Baldwin, March 1979

Method	Calculated Area Infested, ha	Calculated Percent Cover	Kilograms of Hydrilla per square metre			Total Hydrilla, kg		
			$\bar{X}$	LB*	UB*	$\bar{X}$	LB*	UB*
Fathometer tracings	55.3	70.5	1.04	0.80	1.31	576,000	441,620	725,890
Direct biomass sampling	67.4 (78.4)**	86 (100)**	1.2	0.98	1.44	946,640	768,320	1,128,960

* LB = 95 percent lower bound confidence value, UB = 95 percent upper bound confidence value.
** Kilograms hydrilla per square metre and total hydrilla (in kilograms) were calculated from the total area of the lake.

greater than 6 m contains hydrilla. Therefore, it appears a disproportionate amount of sampling effort was placed in hydrilla-infested waters by the direct random biomass sampling method causing an overestimation of the total hydrilla standing crop.

The principal advantage of utilizing a recording fathometer for vegetation surveys is the savings in time and manpower. In Lake Baldwin, 14 transects covering a total distance of 11.32 km were completed in 3 hr. From previous experience, the completion of a 100-m (0.1-km) conventional line intercept transect with points at 2-m intervals requires 0.5 to 1.0 hr for completion and two surveyors. With experience, one person can operate the motorboat and fathometer simultaneously and sample a greater portion of the lake.

Compared to other indirect or noncontact vegetation survey techniques that sample submersed macrophytes, a recording fathometer is advantageous since vegetation is monitored in two planes in the water column: vertical and horizontal. Other methods examine only the water surface or horizontal plane of the water column.

The results of this study indicate that a recording fathometer is best suited for aquatic vegetation surveys in lakes where the problem plant exists as a monoculture. Small beds of eelgrass, though, were distinguishable from hydrilla. Gross morphological differences in plant structure appear to account for variation in recording chart tracing patterns. Future testing may prove that other submersed macrophytes can be differentiated from hydrilla by examination of chart tracing patterns. Our previous tests indicate that differentiation between hydrilla and other submersed macrophytes of similar morphological structure (*Ceratophyllum*, *Myriophyllum*, *Utricularia*, *Cabomba*, and *Egeria*) cannot be accomplished by examination of tracing patterns.

If projects require that different submersed macrophyte species be treated as a group, a recording fathometer could be utilized to generate quantitative data for the entire submersed aquatic plant community. Random direct contact sampling or line intercept transects could be employed to monitor species abundance and diversity. Results of this study demonstrated that fathometer tracing patterns could be correlated with actual hydrilla biomass and the total standing crops of hydrilla in Lake Baldwin could be estimated throughout the year.

The utilization of fathometer tracings for estimation of biomass eliminated the chance of error that occurs when employing a random numbers table for selection of sampling stations. A systematic random approach of selecting biomass prediction stations on chart tracings allowed all water depths to be adequately sampled. Choosing biomass prediction stations containing only hydrilla reduced variation about the mean. By determining predictive independent vegetation variables that were utilized to calculate mean biomass values at 1-m intervals, variation was further reduced in the models. A greater number of hydrilla biomass prediction stations, 152 versus 86 for the biomass samples, were used in the analysis utilizing the fathometer method as compared to direct random biomass sampling method in March 1979 in Lake Baldwin.

One major limitation of the fathometer for estimation of hydrilla biomass and total standing crop was the inability to conduct transects in water depths less than 1 m; therefore, direct estimation of biomass in these water depths was prevented. Also, when formulating predictive regression models correlating fathometer tracing patterns with actual biomass, only two observations in water depths less than 2 m were utilized in the analysis. Therefore, because of limited sampling, biomass estimates from these shallow water areas may be biased. In Lake Baldwin, 9.2 percent of the lake area was less than 2 m in depth. This area contained a small percentage of the total hydrilla standing crop in the lake. Due to these sampling errors, total standing crop estimates were possibly slightly inaccurate.

AQUATIC PLANT CONTROL ACTIVITIES IN THE PANAMA CANAL ZONE

by

Stephen D. Parris*

Background

Since December 1976 WES has maintained an assistance program with the Panama Canal Commission (PCC)** for aquatic plant management. This program has benefited the aquatic plant control programs of both organizations. It has provided WES with a year-round test area for new chemical, biological, and mechanical techniques potentially applicable in the United States. Panama has proven to be especially suited for insect and pathogen work and may yield new insects and microorganisms for use in biocontrol technology. This assistance program has helped the PCC upgrade the qualifications of personnel and modernize the equipment of its aquatic plant control group. They now have an ongoing biocontrol program utilizing the white amur and the hyacinth moth *Sameodes*; they also have the equipment to utilize herbicides superior to the copper sulfate they have used in the past.

Currently, the APCRP of WES and the PCC are in the second year of a 5-year, long-range program. This program is scheduled to continue providing PCC with operational aquatic plant management information, and WES with data useful in its research and development and technology transfer roles.

The assistance program between WES and PCC was initiated late in 1976. LTC Phillip Custer, Assistant to the Director of the Engineering and Construction Bureau of the PCC, visited WES to obtain information on aquatic plant control. The PCC was particularly interested in utilizing the white amur for hydrilla control. However, since the overall aquatic plant control program in the Panama Canal included few state-of-the-art techniques, PCC was also interested in assistance with chemical and mechanical technologies. As an outgrowth of LTC Custer's visit to WES, the assistance program was formally initiated in December 1976. The WES agreed to assist PCC in upgrading its capabilities in chemical and mechanical methods of aquatic plant management as well as providing the specifically requested assistance with the white amur.

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** Formerly the Panama Canal Company.

WES Activities, FY 77-78

One of the first efforts initiated by WES was to obtain aerial photography to determine the amount and location of hydrilla in Gatun Lake, the reservoir through which the canal runs. Color infrared photography at a scale of 1:24,000 was obtained in January 1977. From this film it was determined there were 11,600 acres of hydrilla in Gatun Lake.

During March 1977, PCC approved the proposed programs for insect and pathogen, white amur, chemical, and mechanical programs. From March through November 1977, WES continued work planning the various programs. During November 1977, WES and PCC released the hyacinth weevil *Neochetina bruchi*, in Gatun Lake, and established the hyacinth moth *Sameodes albiguttalis*, in field test cages. November 1977 saw the final publication of the white amur Environmental Impact Statement (EIS) prepared by PCC. By January 1978, it was evident that the initial inoculation of hyacinth moth was a failure, the moths having been destroyed by ants that gained access to the test cages. In addition, two experimental herbicides (EL-171 and E-51) were applied during January 1978.

The initial shipment of white amur to the canal took place in February 1978. Rather than purchase fish that were 1 to 2 lb in size and therefore nonsusceptible to peacock bass predation, the decision was made to stock fingerlings in grow-out areas containing sufficient hydrilla for the amur to reach 1 to 2 lb in weight before their release into Gatun Lake. Fish were transported in a tanker truck that was flown from Little Rock, Arkansas, to the Canal Zone in an Air Force C-130 cargo plane. There was high mortality in this first shipment due to the abrupt temperature change from the cool water of the truck to the warm water of the grow-out area. Mortality of the shipment was estimated to be over 90 percent. Arrangements were immediately made for a second shipment of white amur fingerlings.

During May 1978, there was an additional release of *Sameodes* and *Neochetina*; the initiation of large-scale testing of 2,4-D on waterhyacinth began in June. During August, approximately 144,000 white amur weighing 1 to 2 lb from the second shipment were released from their grow-out area into Gatun Lake, and an additional 177,000 fingerlings from Arkansas were stocked in a separate grow-out area.

The mechanical harvesting test was also completed during August. By September 1978, the hydrilla beds that had been harvested were completely recovered to their previously topped out condition. Hydrilla had been harvested to a depth of 5 ft, and only 6 weeks was required for regrowth.

FY 79 Activities

Personnel from WES and PCC met in the Canal Zone the first week in

March to specify program objectives for the remainder of FY 79. LTC Custer and PCC staff did not wish to continue the mechanical harvesting program. Hydrilla regrowth after previous harvesting efforts was so rapid as to make mechanical harvesting cost prohibitive. The PCC and WES were able to reach an agreement on scheduling and implementation of the program for FY 79.

In order to determine the spread or decline of hydrilla in Gatun Lake during the first 2 years of the program, color infrared aerial photography of the Panama Canal-Gatun Lake area was obtained. The mission was flown from an altitude of 12,000 ft, and the imagery obtained was interpreted by WES. The acreage figure obtained was compared to that obtained from the photo mission flown in 1977. As of March 1979, there were about 12,140 acres of hydrilla in Gatun Lake, as compared to 11,600 acres in 1977, a 4.4 percent increase in 15 months.

Chemical program

An important thrust of the APCRP is the encouragement of field testing of herbicides pursuant to registration for aquatic use. Currently, there are relatively few herbicides available to the Corps of Engineers Districts for aquatic plant management programs. The APCRP has actively cooperated with and encouraged chemical companies to seek Federal registration, and, in the case of registered herbicides, additional data for EPA-approved label modifications. In addition, for the FY 79 test, an important consideration was the development of a field test plan that can be used, with modifications, for testing a variety of aquatic herbicides under the auspices of the APCRP.

The basic test plan for the chemical test in Panama was agreed upon during the March meeting by representatives from WES, PCC, and the Pennwalt Corporation. The herbicides selected were Hydout and Aquathol-K, both of which have endothall as their active ingredient.

The chemical field test began in early April. An area known as the Frijoles Basin was selected and eight plots were established. Each plot was surveyed and mapped and ranged in size from 3.1 to 3.5 acres. Two plots were randomly designated as controls, and the remaining six plots were treated, three with Hydout at 200, 300, and 400 lb/acre, and three with Aquathol-K at 8, 10, and 15 gal/acre. Biomass samples of the aquatic vegetation were taken at the rate of five per acre. Samples were taken before treatment and at intervals of 7, 14, 21, 49, and 84 days after application.

The persistence and dispersion of endothall in the aquatic ecosystem were a primary concern. Samples of water, sediment, and plant biomass were taken within each plot and on the periphery of each plot at days 0, 1, 3, 7, 14, and 21. Endothall residues can be detected only by extremely sophisticated analytical techniques; as part of their contribution to the test, Pennwalt donated the services of their analytical laboratory in Tacoma, Washington, for analysis of all residue samples. Samples were immersed in an ice-brine solution in the field immediately after collection and stored frozen in the PCC commissary to

retard degradation of endothall residues. After day 21 samples were collected, all samples were shipped by air freight on dry ice to the Pennwalt laboratory in Tacoma, Washington.

In addition to herbicide residues, a variety of water quality parameters were monitored both in the field and through laboratory analysis (Table 1). Laboratory analysis of those parameters that could not be measured in the field were performed by the PCC water quality laboratory located in Panama.

Phytoplankton and zooplankton populations were also monitored during studies. Samples were collected through day 21 and are currently being analyzed by a contractor.

Aquathol-K had the most immediate effect on the test plots. Hydrilla within these plots dropped below the surface within 36 to 48 hr after application. Even the lowest application rate, 8 gal/acre, resulted in good control. Only on the fringe areas of several plots, where Aquathol-K was not directly applied, did hydrilla fail to drop out. This may indicate that endothall did not disperse widely after application. Project divers reported that the hydrilla had fallen to the bottom, forming a mat 2 to 3 ft thick. Biomass samples at that time were composed of brown, decomposing hydrilla.

Hydout treated plots responded more slowly. It was 7 to 10 days after application before there was a noticeable decrease in hydrilla. In the lightest treatment plot, 200 lb/acre, control was not achieved.

By July, hydrilla biomass in the Aquathol-K plots was 85 percent of the pretreatment level, with about 60 percent recovery in the Hydout plots. By October, the Aquathol-K plots had recovered fully, while the Hydout plots still had not topped out. Control was maintained on the Hydout plots longer than expected, which may have been due to greater persistence of endothall in the sediment due to the sinking pellet formulation. Sediment residue data will be closely examined in regard to this hypothesis.

Currently, biomass and water quality data are being analyzed at WES, while residue analysis by Pennwalt Corporation is nearing completion. The data will be synthesized at WES during FY 80, and a detailed presentation of the results will be made at the APCRP meeting next year.

Biological program

The primary emphasis of the biological program during FY 79 was on insects and pathogens. Personnel at WES worked with PCC to establish grow-out facilities so a continuing population of *Sameodes* moths for stocking purposes could be maintained in Panama. Temporary grow-out tanks were completed and inoculated with *Sameodes* in July, and a viable population appears to be established. In May and July, samples of indigenous insects, fungi, and bacteria were collected. Work with these specimens is continuing at WES in hopes that new biocontrol agents will be identified. In addition to the fieldwork, information pertaining to *Cercospora rodmanii*, a fungal pathogen of waterhyacinth,

Table 1

Water Quality Parameters Monitored in Test Plots

Monitored in the Field	Analyzed in Laboratory
Specific conductance	Total alkalinity
Dissolved oxygen	Color
pH	Hardness
Water temperature	Total Kjeldahl nitrogen
Secchi disk reading	Ammonia nitrogen
	Total phosphate
	Dissolved solids
	Biological oxygen demand
	Turbidity

was delivered to PCC for inclusion in an Environmental Impact Assessment (EIA) for future testing.

Planned FY 80 Activities

In September 1979, a team from WES returned to Panama to discuss the program for FY 80. Personnel at PCC were interested in maintaining the program with WES, but the political situation at that time made future planning difficult. Basic questions concerning funding of the new Panama Canal Commission had not then been resolved in Congress. With this in mind, a scaled-down program for FY 80 was established. There will be no further effort in mechanical haresting and no WES-coordinated chemical field tests, although WES will continue to provide information in these areas if requested. The primary effort will continue with the biological program. During FY 80, additional insect and pathogen samples will be collected, and damage at field test sites will be evaluated. Identification of pathogens collected will continue at WES. The WES personnel will also assist PCC in their culture and release of *Sameodes* and the field test of the fungal pathogen of waterhyacinth *C. rodmanii*. In a related effort, WES personnel will work with USDA in collecting and evaluating the moth *Paraponyx rugosalis* for future testing.

The WES has a limited work schedule planned for Panama in FY 80. As part of the Aquatic Plant Problem Identification and Assessment Project, WES is planning to field test a variety of aerial photography techniques in the canal this spring. The opportunity will also be taken to verify the extent of aquatic plant infestations in Gatun Lake as previously indicated by color infrared imagery. This aerial photographic ground truth exercise will give additional information on the accuracy limitations of the imagery studies.

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

United States. Waterways Experiment Station, Vicksburg, Miss.

Proceedings, 14th Annual Meeting, Aquatic Plant Control Research Planning and Operations Review, 26-29 November 1979, Lake Eufaula, Oklahoma. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1980.

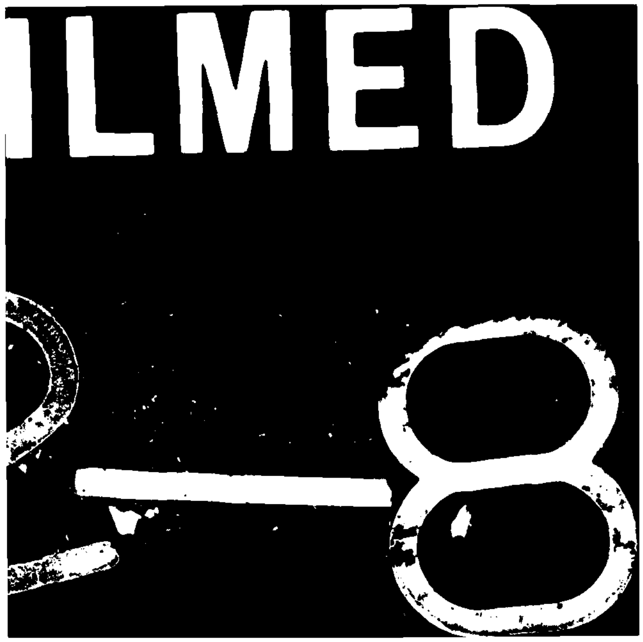
389 p. : ill. ; 27 cm. (Miscellaneous paper - U. S. Army Engineer Waterways Experiment Station ; A-80-3)

Prepared for Office, Chief of Engineers, U. S. Army, Washington, D. C.

Includes bibliographies.

1. Aquatic plant control -- Congresses. 2. Research planning -- Congresses. I. United States. Army. Corps of Engineers. II. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Miscellaneous paper ; A-80-3.

TA7.W34m no.A-80-3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